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Optimal strategies for sustainable household organic material management in the city of Rochester, NY

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A thesis presented

by

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Notice

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Optimal strategies for sustainable household organic material management in the city of Rochester, NY

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Presented in partial fulfillment of the requirements for the degree of Master of Science in Sustainable Systems and accepted on behalf of the Rochester Institute of Technology by the thesis committee.

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Abstract

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Title: Optimal strategies for sustainable household organic material management
in the city of Rochester, NY

The purpose of this research was to explore the benefits and challenges of implementing a sustainable system for managing household organic material (HHOM) in the city of Rochester, NY. Elsewhere in the United States and the world, HHOM (i.e. excess food, yard matter, and compostable paper) has been increasingly diverted from landfills to organic waste-to-energy and composting pathways (European Environment Agency 2013a; Skumatz and Freeman 2006). Landfill diversion is enabled by municipal projects that support source separation of HHOM out of the municipal solid waste (MSW) stream, thereby extracting valuable organic resources for higher-value processing (NYSDEC 2010). This has been done to increase the profitability of HHOM management (Eriksson et al. 2005) while simultaneously achieving benefits to the environment (e.g. life-cycle greenhouse gas reductions) (Ebner et al., 2014; Sanscartier et al. 2012; Environmental Protection Agency 2013c) and society (e.g. community resilience; food security; local agriculture) (Sundkvist et al. 2001; Curtis 2003; Jansson 2013; Colding and Barthel 2013). In recent years, only 10% of the 27,000 Metric Tons (MT) of HHOM in the city of Rochester has been diverted from landfills (NYSDEC 2008). It was hypothesized in this research that an effectively planned and implemented municipal project designed to increase processing of HHOM in organic waste-to-energy or composting pathways would sustainably bolster economic, social, and environmental assets in the city of Rochester, NY.

The first step in testing this assertion involved gathering data on the social sustainability of a project utilizing source separated HHOM. Surveys and interviews of potential project participants in the Southeast section of the city of Rochester, NY were conducted to examine residents' a) likelihood of project participation, b) economic incentives to reduce MSW generation and HHOM

source separation, c) current HHOM management behaviors, and d) awareness of available HHOM management pathways. Resident survey and interview responses indicated that residents are likely to reduce MSW generation and to participate in curbside collection of source separated HHOM, as long as these goals are incentivized. In addition, composting was found to be the most well-known pathway for HHOM management. Additional education is required to increase awareness of the other pathways for managing HHOM, yet residents indicated that they are interested in purchasing pathway products (i.e. locally produced energy and compost).

The survey and interview data indicated a need for incentivizing sustainable HHOM management behaviors. Thus, it was essential to determine the most cost-effective municipal project to drive source separation of HHOM. A literature review was conducted of projects in locales achieving high landfill diversion of HHOM to identify the best policy options. The findings indicated that the ideal project to support source separation of HHOM in Rochester, NY is weight-based MSW pricing (also known as pay-as-you-throw) with free organic collection. The financial impacts of implementing a pay-as-you-throw (PAYT) project in the city of Rochester, NY were analyzed using a cost-benefit analysis (CBA). Development of the CBA model addressed the uncertainty in the financial impacts of implementing the PAYT project by conducting the analysis for multiple scenarios of key parameters such as actual resident HHOM source separation and MSW reduction behaviors. Data required to build scenarios was based on documented source separation and MSW generation performance for new and established PAYT projects. For each scenario, optimal MSW prices were found where municipal budget was maximized without reducing the average household budget. Then, project net present value was calculated.

Weight-based PAYT project net present value (NPV) to the municipal solid waste collection budget for the City of Rochester Department of Environmental Services was calculated. The project NPV is between $12,100,000 and $18,100,000, with a projected increase in average city household budget over the 11 year project life. The project was shown to have annual positive net cash flows between $1,300,000 under a conservative MSW source reduction scenario and $2,100,000 with an optimistic source reduction scenario. At current City of Rochester solid waste collection budget levels of $17,300,000, the project would reduce annual expenditures by 8% (City of Rochester, NY 2013a). Finally, under the PAYT project examined in this research, city of Rochester residents would produce 10,000-20,000 MT less MSW.

The surveys, interviews, and CBA showed the promise of implementing a project to utilize source separated HHOM. However, it remained unclear what local pathways were economically optimal (i.e. profit-maximizing) for processing excess food, compostable paper, and yard trimming feedstocks from households in the city of Rochester, NY. The product yields, costs, and revenues are

different for HHOM processing pathways, and can depend on the chemical properties of feedstocks. Due to these uncertainties, investment in sustainable HHOM infrastructure could be stymied unless the most profitable HHOM management pathways are identified. This was investigated by creating an engineering-economic model using the What'sBEST! Add-in for Microsoft Excel. The model looked at four management pathways for source separated HHOM: landfills with gas capture (i.e. *status quo* for Rochester, NY), plus anaerobic digestion (AD), simultaneous saccharification and fermentation (SSF), and windrow composting. Model indicators included pathway revenues (e.g. product sales and tipping fees), pathway costs (e.g. trucking, capital, operations), as well as feedstock chemical parameters. Empirical data was collected for biomethane potential (mL CH_4 /g volatile solids) of representative HH food and compostable paper material using gas chromatography. Baseline results indicate that $3,000,000 in profit can be made from HHOM with profit-maximizing processing pathways. In the baseline, anaerobic digestion was optimal for food, SSF was optimal for yard trimmings, and composting was optimal for compostable paper. Landfills with gas capture were not economically optimal for the HHOM feedstocks. In the case of a single-stream HHOM collection scheme, the baseline model shows that anaerobic digestion is the most profitable pathway. Sensitivity analysis showed that product revenues were the primary drivers of profitability among profit-maximizing HHOM pathways. On the other hand, pathway tipping fees and feedstock trucking costs have a relatively minimal impact on profits. This research showed that updating HHOM management policy and practice in the city of Rochester, NY will maximize local environmental, social, and economic performance. This can and should be achieved with the expansion of AD, composting, and SSF infrastructure in place of landfills with gas capture.

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Nomenclature

Abbreviation	Name
ABCD	Asset-based community development
AD	Anaerobic digestion
BMP	Biomethane potential
C:N	Carbon to nitrogen ratio
CBA	Cost-benefit analysis
CC	Community Composting, LLC
CO_2	Carbon dioxide
CO2-eq	Carbon dioxide equivalent for global warming potential
CoEAT	Co-digestion economic analysis tool
COM	Commercial composting
EEA	European Environment Agency
EPA	United States Environmental Protection Agency
EU	European Union
GC	Gas chromatography
GHG	Greenhouse gas
HH	Household
HHMSW	Household municipal solid waste
HHOM	Household organic material
HPLC	High-performance liquid chromatography
LF	Landfill (with gas capture)
LHV	Lower heating value
LLC	Limited liability company
MJ	Megajoule
mmBTU	Million British Thermal Units
MSW	Municipal solid waste
MT	Metric tonne (or 1,000 kilograms)
NFP	Not-for-profit enterprise
NPV	Net present value
OC	Organic collection
PAYT	Pay-as-you-throw municipal solid waste pricing policy
PED	Price elasticity of demand
SR	Source reduction
SSF	Simultaneous saccharification and fermentation (or simply "fermentation")
TS	Total solids
US	United States
VS	Volatile solids

Chapter 1: Introduction

There is no such thing as organic waste – only wasted organics.

a. Imperatives of sustainable human development

Most of the systems of humankind are having such enormous impacts on our environmental systems that they counteract the primary goal of civilization: better lives. From natural resource depletion to environmental contamination, society is unsustainable and getting worse quickly (Sterman 2012). The engine of human development is headed toward a steep cliff, and we need to change course while we still can. This may be accomplished by meeting the current technical, economic, social, political and indeed personal challenges borne from human systems that do not maximize sustainability.

In addition to being a theoretical concept that is relevant in diverse contexts and disciplines, *sustainability is systems science that enables smart development*. Sustainability is pursued by applying tools to analyze human impacts on the world. From there, informed action is implemented in communities to promote human flourishing. These actions occur in perpetuity – generation after generation.

Sustainable systems are interconnected, fast changing units that encompass environmental, social, and economic domains. The most valuable domain is the environment, from which human social and economic resources are derived. There can be no healthy firms, healthy economy and healthy people if growth destroys the environment. Nor can we have a healthy environment if people live in poverty, without economic opportunity (Sterman 2012). Presently, there is a tension between growth and environmental degradation indicating a need for investigation of its cause. The systems science of sustainability seeks out seemingly competing and exclusive interests (such as economic expansion and environmental protection) that are fundamentally intertwined. It is at these intersection points where practical and economic, social, and environmental opportunities arise.

When sustainability informs human development patterns, sustainable development is achieved. Thus, the implementation of sustainability is the process of sustainable development. Although there is no unified theory of sustainable development, there is a general agreement that the essential requirements of sustainable development are: a) poverty eradication; b) changing production and consumption patterns; and c) managing natural resource bases around the globe (United Nations 2002). The specific roadmap for sustainable development depends on the local conditions within a system boundary (e.g. a community) which may be as large as the globe or as small as a household.

The importance of protecting the Earth's environmental system for the benefit of the interconnected economic and social systems was first recognized on the international level in 1972 at the United Nations Conference on the Human Environment in Stockholm (United Nations Environment Programme 1972). Two decades later, the classic blueprint for sustainable development was produced at the 1992 United Nations Conference on Environment and Development in Rio (i.e. Agenda 21). It argued that high-income countries are primarily responsible for today's global environmental stresses due to the particularly resource-intensive lifestyles and practices of their citizens, governments, and businesses. Sustainable development requires everyone to reduce environmental stresses in accordance with their means, and participate in the collective pursuit of better social and economic well-being (UNCED 1992). In spite of the international recognition and attempted implementation of sustainable development principles, long-term environmental degradation and wasteful management practices have outpaced progress toward sustainability.

For individuals, sustainable development is directly tied to the adoption of *sustainable lifestyles* and *sustainable consumption* – that is changing behavioral and consumption patterns in order to both minimize the use of resources and enhance well-being. History has shown that accelerating this transition is usually not easy. There is a strong causal relationship between well-being and affluence, but increasing affluence is associated with additional material consumption. In order to gain affluence without more intense resource consumption, sustainable technological and cultural changes must occur. Overall, sustainable resource management technologies and practices are opaque to the public and are therefore far from being institutionalized in government, business, or household practices.

There are many technological applications readily available to promote sustainable development in local systems by improving resource management. A separate but connected challenge involves culture that enables effective implementation of the proper technologies. The cultural side of the scientific dialogue on promoting sustainable (resource efficient) behavior focuses on the link between pro-environment/pro-social values and behaviors (McKenzie-Mohr 2000; Kollmuss and Agyeman 2002). Problematically, there is weak scientific evidence of a causal link between sustainable lifestyle behaviors and awareness of individual environmental impacts. That is to say that there is a discrepancy between the adoption of sustainable actions and sustainable values (Gatersleben 2010). As of yet there is no scientific consensus on how to address this.

b. Organic material management: a solution to degrading environmental-economic systems

Climate change caused by anthropogenic greenhouse gas (GHG) emissions is one of the greatest long-term vulnerabilities to the globe, and threatens New York State's ecological-economic system. Communities and local governments have the responsibility to take a more aggressive stance toward reducing their vulnerability to climate hazards through sustainability planning efforts. In order to reduce vulnerability, GHG emissions must approach equilibrium, which is a state of balance between GHG sources and sinks (Sterman 2012).

Electricity generation is the largest U.S. greenhouse gas emissions source, accounting for about 32% of total U.S. greenhouse gas emissions since 1990. Transportation is the second-largest source of greenhouse gas emissions, accounting for 27% of emissions since 1990 (Environmental Protection Agency 2013d). In 2011, methane accounted for 9% of U.S. emissions. Of that, nearly 20% of methane emissions come from waste management via decomposition of the organic fraction of solid waste in landfills (Environmental Protection Agency 2013e). Methane control is critical since it is a potent greenhouse gas – methane has over twenty times the global warming potential as carbon dioxide on a one hundred year time scale, with an even more severe warming effect on shorter time scales (UNFCCC 1995).

GHG emissions from electricity generation, transportation, and landfills can be addressed through local organic waste-to-energy systems using pathways such as anaerobic digestion (AD) and simultaneous saccharification and fermentation (SSF) (pathways explained at length in Chapter 2). With those organic waste-to-energy pathways it is possible to use wasted household organic resources to (1) prevent methane emissions from landfills by diverting organic material, (2) offset transportation emissions via fuel-grade ethanol production, (3) offset electricity generation emissions via methane gas production, and (4) produce valuable co-products such as compost and animal feed. Co-products also offset emissions because they prevent the purchase of those same products on the market, which require energy to create. Additionally, compost co-product in particular can be used in agriculture and plays a key role as organic matter in the reduction of GHG emissions derived from food production (Mondini et al. 2008).

Organic material management practices that emphasize material recovery (i.e. diverting material from landfill and re-processing it) are shown to reduce GHG reductions in municipal and private contexts (Barton et al. 2008). Figure 1.1 shows how municipalities in Europe have reversed a rising trend in GHG emissions from municipal solid waste (MSW) management. MSW is defined as solid materials generated within a community from residential, commercial, and institutional origins. Europe has achieved significant aggregate GHG reductions over the past two decades from

MSW management by reducing direct emissions from landfilling material, and by avoiding emissions through material re-processing (i.e. remanufacturing of goods from wasted materials).

Europe's GHG reductions have mainly not come from landfill-gas-to-energy systems. Although they are widely deployed in Europe, they make a very small contribution to avoided emissions (see Figure 1.1 "avoided emissions: landfilling") (European Environment Agency 2013a). Incineration has also played an immaterial role in GHG reduction from MSW management. From 1990 to 2010, the marginal impact of incineration has been to produce slightly more direct emissions than it avoids (Figure 1.1), which means that it is not contributing to overall GHG reduction. These findings point to the ineffective nature of landfill gas-to-energy and incineration pathways for reducing MSW management emissions.

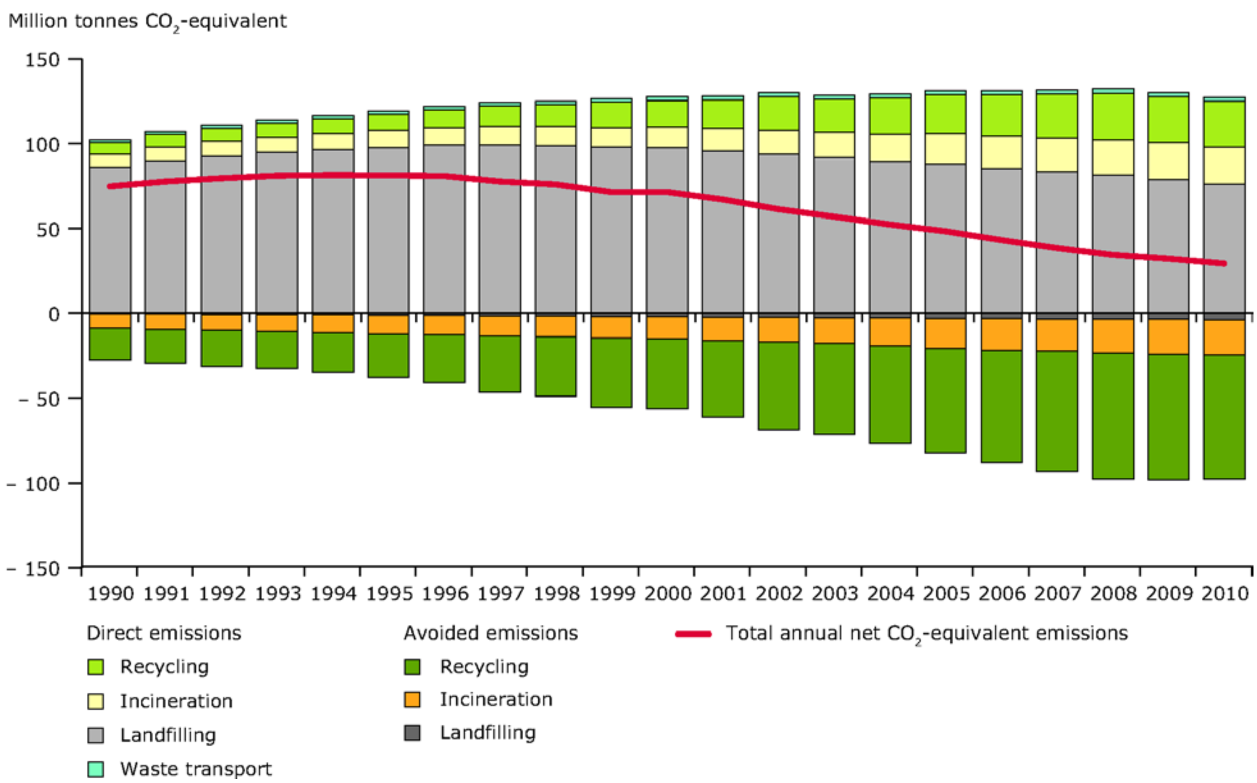


Figure 1.1: Net GHG emissions from municipal solid waste management in Europe (European Environment Agency 2013a)

Organic material recycling or reprocessing is prevalent in Europe. For example, Sweden effectively uses source separated organic material to generate biogas via community-scale anaerobic digestion. The municipal biogas is used for: combined heat and power (CHP) electricity generation; compressed natural gas (CNG) vehicle filling stations; home use; and public transportation in busses. A life cycle assessment of MSW management scenarios in three different Swedish municipalities (Stockholm, Uppsala, and Älvdalen) found clear environmental and economic benefits to anaerobic digestion over landfilling (Eriksson et al. 2005). The study compared landfilling of MSW with 70% source separation of organic material for anaerobic digestion to make biogas powering electric generation, busses, and cars. The results showed that all the anaerobic digestion scenarios had: significantly lower global warming, acidification, and eutrophication potentials; lower primary energy use; and lower total financial costs (Eriksson et al. 2005). As the Swedish case shows, achieving GHG reductions from organic MSW management is enabled by using local material processing pathways.

Near the city of Rochester, NY there are multiple organic material processing pathways that have been recently deployed over landfills with gas capture – namely anaerobic digestion (AD), commercial composting, and simultaneous saccharification and fermentation (SSF). The primary study of an organic material management pathway within the city of Rochester, NY was performed by Ebner et al. (2014). Their findings suggest that an organic waste-to-ethanol process within city limits offers significant potential for GHG emission improvement. Utilizing the local SSF pathway to convert source separated household organic material to ethanol, compost, and animal feed has the added benefit of satisfying local product demand while offsetting external production, thereby reducing virgin material and energy use. The study results showed a net carbon negative process, with 554% well-to-wheels improvement in GHG impacts relative to corn ethanol and 460% relative to conventional gasoline (Ebner et al. 2014). The SSF process was determined carbon negative for all scenarios with landfill avoidance.

There is a lack of research on the local GHG reduction impacts of anaerobic digestion and composting, however data from other locations is promising. For AD, Sanscartier et al. (2012) examined the life-cycle GHG emissions from a household source separated organic material collection program in Ontario, Canada. The source separated material is processed at the Dufferin Organics Processing Facility (located locally in Toronto, Ontario). This AD facility is the only one in North America that currently processes household source separated organic material as a sole feedstock (Sanscartier et al. 2012). Use of anaerobic digestion was found to reduce management system GHG emissions relative to a landfill that captures 75% of landfill methane emissions. The avoided emissions from AD range from -0.1 to -0.3 MT CO_2-eq/MT household organic material depending on the AD plant methane yield (Sanscartier et al. 2012).

Available data from the United States Environmental Protection Agency (USEPA) Waste Reduction Model (WARM) shows significant reductions can be achieved through utilizing the composting pathway over landfills with gas capture. The avoided GHG emissions due to composting versus landfills with gas capture are -0.6 MT CO_2-eq/MT food and -0.58 MT CO_2-eq/MT yard trimmings (Environmental Protection Agency 2013c). No primary data exists on the compostable paper specifically. However, USEPA WARM reports an emissions factor of -0.24 MT CO_2-eq/MT for mixed organics (Environmental Protection Agency 2013c). Although mixed organics are not compostable paper, they contain compostable paper and show the potential for GHG reduction by composting the material.

In spite of existing work showing the environmental benefits using SSF, AD, and composting pathways instead of landfills with gas capture for managing household organic material, the practicality of expanding the alternative processing pathways has not been examined for the city of Rochester, NY. First of all, no data has been gathered about whether or city residents will participate in the system by source separating their household organic material for collection. Without access to feedstocks, there can be no private sector development of AD, SSF, and composting to capture the sustainability benefits of household organic material. This gap was addressed in this work through city resident surveys and interviews regarding social sustainability of a sustainable HHOM system.

Second, although feedstock access is a prerequisite for the development of a sustainable household organic material management system, there has been no research seeking to determine an effective policy approach to incentivize residents to source separate their organic material. Third, from a municipal policy perspective, it is unknown whether setting up and enforcing such a policy incentive would be financially feasible in the short and long terms. This combination of questions has not been attempted before for a municipality, and this research addresses the opening through literature review and cost benefit analysis of an economic incentive policy to promote HHOM source separation. Lastly, decision-makers need to know the relative profitability of these four material management pathways in the city of Rochester, NY in order to reduce the entrepreneurial risks associated with developing new businesses that process household organic material. This issue has not been framed this way to date, so an engineering economics model was developed to determine the profit-maximizing management pathways for different types of HHOM.

c. Definition of household organic material

Household organic material (HHOM) is defined as MSW generated at the residential level that includes three specific materials (Environmental Protection Agency 2013c):

- **Yard trimmings**: grass, leaves, trimmings from trees and brush from household landscaping or gardens.
- **Excess food**: uneaten food from households.
- **Compostable paper:** used paper products (e.g. paper towels, food-contaminated paper and cardboard, tissues, and napkins). These materials are *not* compatible with traditional paper recycling processes that would handle newspaper, office paper, or corrugated cardboard.

In terms of chemical composition, there are other materials in the MSW stream that are organic in that they consist of natural or synthetic organic compounds made with carbon, hydrogen, and oxygen. Examples are wood, clean paper, and some plastics. However, these materials are not the focus of the sustainable material management strategies in this research because unlike yard trimmings, excess food, and compostable paper they: 1) have mature infrastructures for post-consumer re-use; 2) are not compatible with the available processing pathways in the city of Rochester, NY; and 3) tend to have higher landfill diversion rates. As such, this research generally refers to industrially relevant HHOM – i.e. yard trimmings, excess food, and compostable paper.

d. Sustainable organic material management in European nations

Although sustainable management of organic material is lagging in the United States, significant changes can occur quickly. The European Union (EU) is a good benchmark for growth predictions. The EU is a world leader in organic diversion, and member states have tried many strategies to boost organic material re-use while tracking diversion data. The EU experience with organic recovery serves as a bank of case studies that show what American organic recovery could look like in the future. Over the past two decades, the EU has increased the amount of organic and non-organic MSW recovered in non-landfill pathways. By 2009 the EU saw the mass of MSW going to landfill decrease 32% relative to 1995. Over the same time period, the incineration pathway increased its mass throughput by 63%; paper, glass, and metal recycling mass throughput increased by 172%; and the mass of organics composted rose 239% (European Commission 2011).

The European Environment Agency (2013a) issued report outlining the achievements of 32 member-states in their MSW diversion efforts, spurred on by a strict directive of 50% landfill diversion by 2020 (European Environment Agency 2013a). They found that from 2001 to 2010, there is a clear indication of a shift away from landfilling toward alternative management approaches. This is indicated by a sharp decrease in the number of countries that landfill more than 75% of MSW, and by the fact that MSW diversion rates climbed at least 10% in 12 member countries. Over the same time period, growth in organic diversion rates have lagged behind other materials such as cardboard, plastic, and glass – similar to the US. The report showed a large amount of variation between different regions indicating that regional policies have a significant influence on diversion rates, and that local policy changes weigh heavily on the sustainability of the material management system.

With respect to organic material specifically, Figure 1.2 shows the progress in organic diversion rate among EU member states from 2001 to 2010. The organic diversion rate is calculated as percentage of recovered organic material per kg municipal waste generated. Recovered organic material has avoided the landfill and undergone anaerobic digestion or composting. The highest performer (Austria) had a recover rate in excess of 30% - over three times higher than the recovery rate in the US. Fourteen of the thirty-two member states achieved higher recovery rates than the US. Clearly the US has farther to go in order to be at the forefront of sustainable organic material management, and can learn from EU member states.

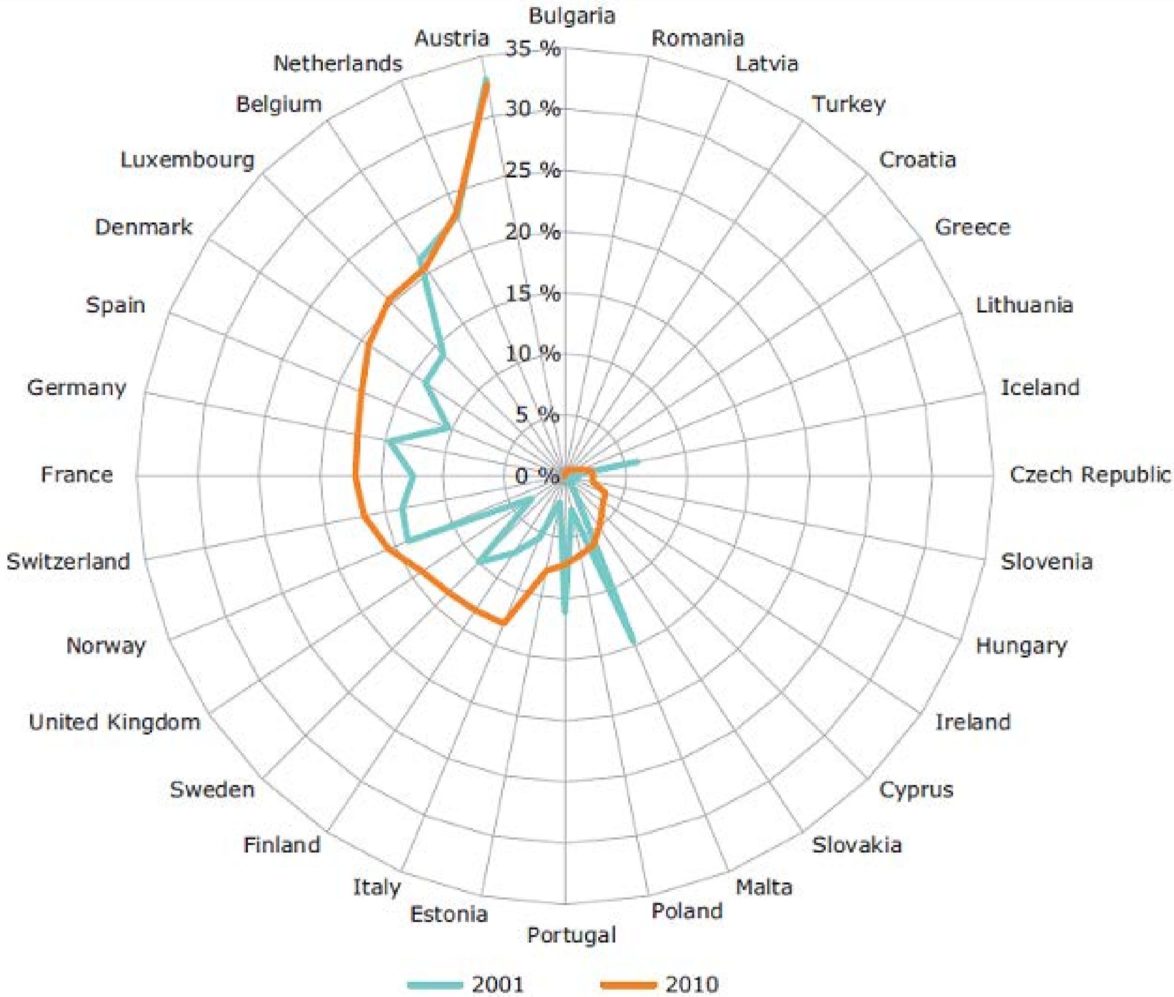


Figure 1.2: Organic ("bio-waste") diversion rates as a percentage of municipal waste generation in 32 European countries, 2001 and 2010 (European Environment Agency 2013a)

e. The state of United States organic material management

The United States Environmental Protection Agency has outlined a hierarchy for food diversion in particular, which is pictured in Figure 1.3 (Environmental Protection Agency 2013a). It shows that the top policy goal of food material management is source reduction – that is generating less excess food to begin with. Aiming to achieve source reduction is a beneficial framework to manage other household organics (i.e. yard trimmings, compostable paper) since source reduction requires no greenhouse gas-intensive processing to eliminate the impacts of organic waste. Source reduction is often achieved by policies that encourage households to separate organic material from MSW (i.e. unit pricing or pay-as-you-throw). In addition to being an important environmental goal, source reduction has economic impacts on MSW collection programs by altering municipal collection revenues, trucking costs, and landfill tipping fees. Chapter 4 of this research examines the overall municipal budget impact of a weight-based MSW unit pricing impact in the city of Rochester, NY under three source reduction behavior scenarios.

When source reduction is not sufficient to reduce waste, there are other management pathways to consider: feeding people, feeding animals, organic waste-to-energy, composting, and finally landfilling. After efforts to improve source reduction have been made, feeding hungry people and then livestock are the preferred routes. When food is not suitable for human or animal consumption, organic waste-to-energy becomes the most viable option (Environmental Protection Agency 2013a). As Figure 1.3 shows, the last resort for managing excess food should be landfilling and incineration – even when gas capture is being used to mitigate methane emissions and generate energy.

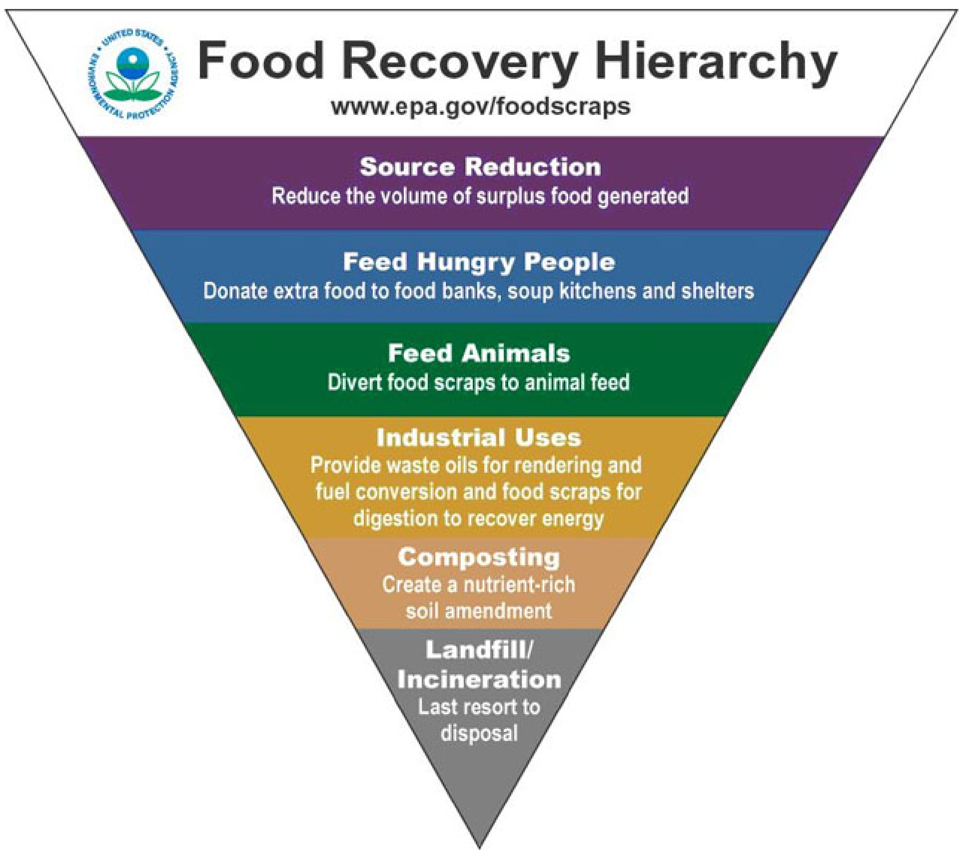


Figure 1.3: Hierarchy of uses for recovered food from the Environmental Protection Agency (Environmental Protection Agency 2013a)

The local SSF process examined in Ebner at al. (2014) acts at all levels in the EPA Food Recovery Hierarchy excluding landfill/incineration. During processing, a nutritional co-product is created in addition to ethanol, which is fit for both human and animal consumption. This co-product is made from the residual (post-fermentation) solids with small particle size. Thus, the local SSF pathway recirculates food back up the hierarchy from industrial uses to feeding hungry people or animals (Environmental Protection Agency 2013a). Human food production from SSF offsets food production from traditional agriculture, thereby cutting the environmental impacts of from agricultural inputs such as fertilizer, water, and fuel. An added benefit is that SSF does not contribute to higher food prices since a wasted organic feedstock was used in production.

It is estimated that 40% of food is wasted in the United States (Gunders 2012; Gustavsson et al. 2011). Nationwide consumer and municipal food losses account for over twice the losses at any of the other supply chain steps (i.e. production, post-harvest handling, packaging, and retailing) (Gunders 2012). There are economic and cultural reasons for food waste in the US. In industrialized countries, food gets lost when production exceeds demand. In the case of surplus production, some of the residual crops are sold to processors or as animal feed. However, this pathway is not financially profitable considering lower prices in these sectors compared to those from retailers (Gustavsson et al. 2011). There is a need to investigate the extent of new opportunities for managing this material in potentially more profitable pathways such as AD, SSF, and composting.

Nationwide, 54% of all MSW generated goes to the landfill – down from 94% in 1960 (Environmental Protection Agency 2013b). This is mainly due to gains in paper, metal, glass, and plastic recycling infrastructure. According to nation-wide EPA data, material recovery in these areas is on the rise – up to a combined 34.7% in 2011 from 33.1% in 2007. However, it appears that the national growth of organic material diversion is faltering – down a combined 5% in the last five years on record (Environmental Protection Agency 2013b). The outcome has been higher percentages of organic material ending up in the landfill than any other material. By comparing US material recovery rates in Figure 1.4 for clean paper, glass, and metals against Figure 1.5 for household organic materials, we see how yard material has caught up to these conventional recyclables, while food has remained practically unutilized (Figure 1.5; calculation in appendix A).

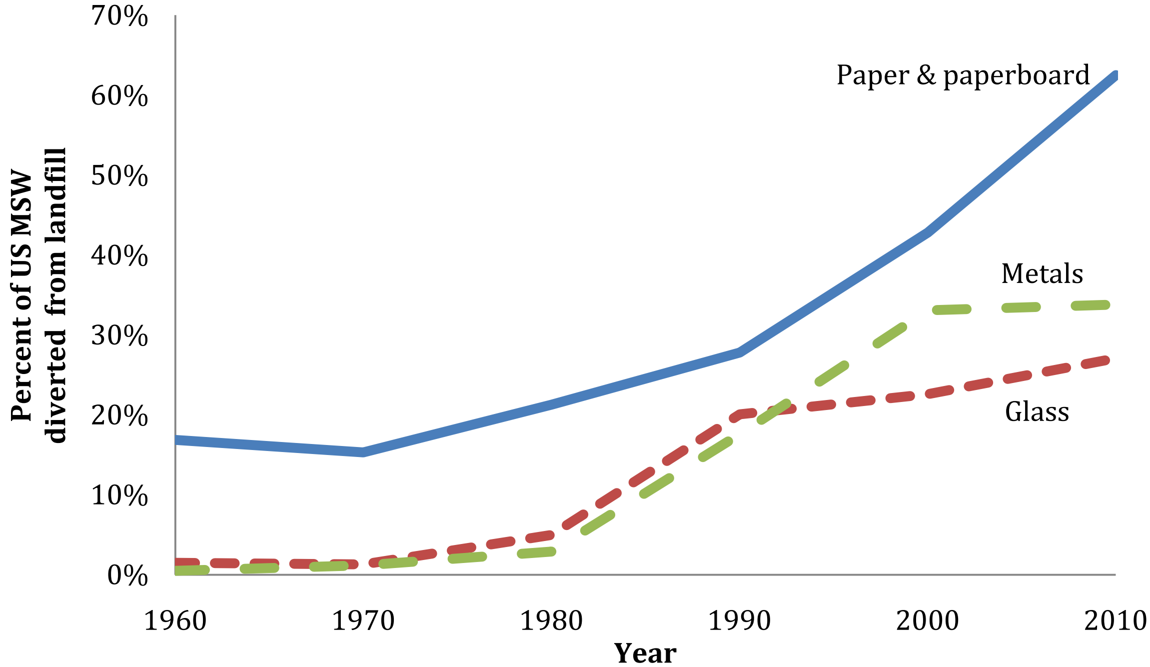


Figure 1.4: Non-organic material recovery (i.e. diversion from landfill) from MSW in the United States (1960-2010) (EPA 2011)

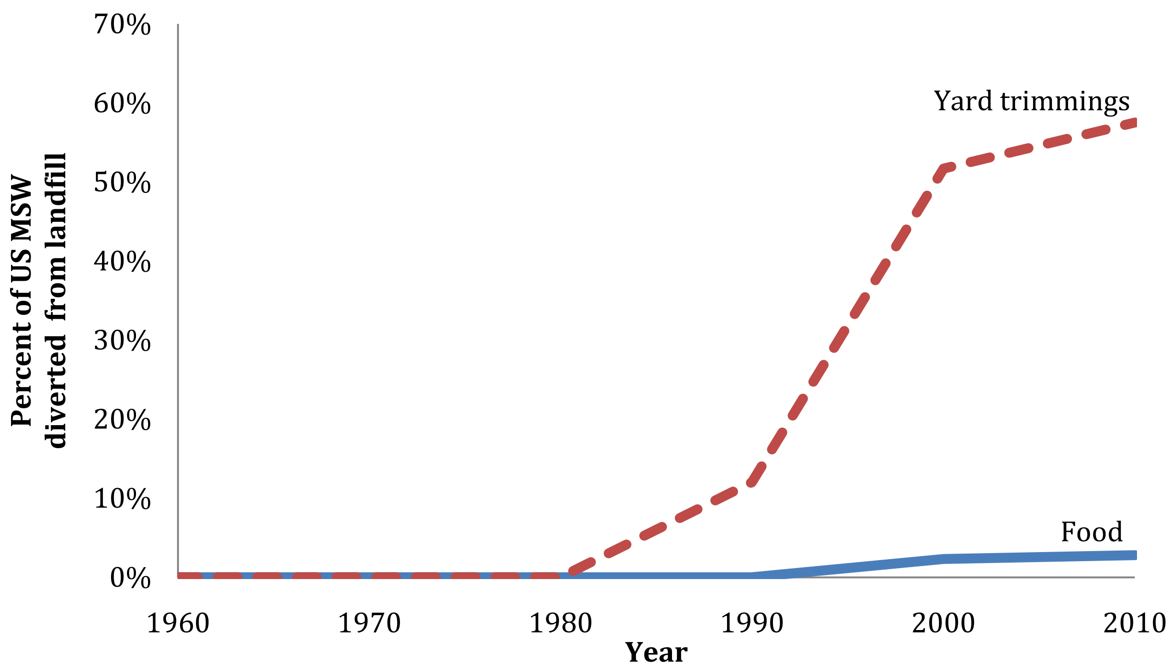


Figure 1.5: Organic MSW material recovery (i.e. diversion from landfill) in the United States (1960-2010) (EPA 2011)

The yard trimming diversion rate dwarfs that of food 58% to 3% respectively. While yard trimmings exceed many other widely collected items such as glass and plastic (especially since 2000), food diversion rate has barely increased from its modest start in 1990.

It is useful to point out that the 2013 "Municipal Solid Waste: Facts and Figures" EPA study methodology for deriving the organic recovery totals only considered the composting pathway. First and foremost this means that other pathways (e.g. AD, SSF, and pyrolysis) are very seldom used in the US. Secondly, since what is measured reflects the values of the organization recording the data, the EPA methodology goes to show that other organic recycling pathways are not broadly recognized by decision-makers across the United States. This helps explain the stagnancy of organic recovery across the nation.

In Europe, anaerobic digestion technology has proven to be a successful component of sustainable organic material management for many decades, existing alongside composting. In the United States, anaerobic digestion technology has traditionally been used to manage bio solids at waste-water treatment plants. More recently they are being used in agriculture for manure management and by municipalities for the handling of the organic portion of municipal solid waste.

In the 2013 "Municipal Solid Waste: Facts and Figures" EPA assessment of organic waste-to-energy in the US, AD and SSF pathways were not tracked. Most of the organic waste-to-energy in the US occurs without source separation as a volume reduction practice, particularly in the Northeast. There is a relatively small fraction of source-separated incineration in the US (3.3 million tons out of 250 million tons generated), mainly from tires or wood and paper waste that are added to boilers burning another type of fuel.

f. City of Rochester, NY household organic material management opportunities & challenges

f.1 Diversion of household organic material from landfills

As Table 1.1 illustrates, there is an economically and environmentally significant amount of excess food, yard trimmings, and compostable paper being produced within the city of Rochester, NY (ranking 1, 5, and 9 respectively in total generation). Diverting these materials requires particular attention by virtue of their large contribution to total generation. Additionally, reducing landfilling of these relatively environmentally benign materials will save local landfill space for more hazardous materials that cannot be recycled. As Wagner noted in his 2011 article "incentivizing sustainable waste management", since landfills will continue to be a necessary part of society's economic engine for many years, true sustainable waste management involves optimizing the use of landfills to attain their highest value. Unlike hazardous materials or many bulky consumer goods, food, yard trimmings, and compostable paper are organic and easily biodegradable. These properties indicate that there are proven alternative management pathways for achieving superior economic and environmental value compared to landfilling.

The landfill diversion rates of these materials are mixed. Yard trimmings are diverted from landfills the most often out of any category, and are usually composted. On the other extreme, diversion of food and compostable paper are ranked dead last of all materials in spite of being ranked 1 and 5 respectively in generation. There is clearly an opportunity to collect the material and use it in alternative pathways that create higher value than landfills. Utilization of these pathways (e.g. anaerobic digestion, composting, and SSF) is robust in the European Union. Diversion of household organic materials has been steadily increasing there over the past several decades.

Table 1.1: Ranked material composition and landfill diversion of municipal solid waste in New York State (NYSDEC 2008)

Material	Tons Generated	Percent of Total Generation	Generation Rank	Percent Diverted from Landfill	Diversion Rank
Food Scraps	**3,232,976**	**17.70%**	**1**	**1.00%**	**18**
Other Recyclable Paper	2,172,639	11.90%	2	25.50%	9
Miscellaneous	1,965,717	10.70%	3	3.70%	14
Corrugated Cardboard	1,831,317	10.00%	4	52.50%	3
Compostable Paper	**1,223,244**	**6.70%**	**5**	**0.30%**	**19**
Other Plastic	1,144,074	6.30%	6	1.30%	17
Film Plastic	1,052,565	5.80%	7	1.70%	16
Textiles	948,516	5.20%	8	4.20%	12
Yard Trimmings	**919,770**	**5.00%**	**9**	**67.10%**	**1**
Other Ferrous Metals	794,581	4.30%	10	30.70%	8
Newspaper	744,095	4.10%	11	66.20%	2
Glass Containers	729,687	4.00%	12	44.60%	5
Wood	638,372	3.50%	13	4.40%	11
Aluminum Containers	290,429	1.60%	14	39.90%	7
PET Containers	184,677	1.00%	15	46.70%	4
Other Non-Ferrous Metals	176,839	1.00%	16	44.30%	6
HDPE Containers	155,220	0.90%	17	19.70%	10
Other Glass	71,926	0.40%	18	1.90%	15
Other Plastic (3-7) Containers	35,394	0.20%	19	4.20%	13
Total	18,312,038	100%	-	20.30%	-

Over half of the MSW stream comes from urban areas – indicating a need to focus on organic material management in the urban context in particular (NYSDEC 2008). Three organic materials – food, yard trimmings, and compostable paper – make up 33% of all MSW generated in Rochester, NY. Roughly half of that is from household sources (or 15% of total MSW generated). As Figure 1.6 shows, the total amount of these household organic materials with suitable characteristics for organic waste-to-energy processes is over 27,000 metric tons (MT) annually for the City of Rochester, NY – approximately equivalent to the combined commercial and institutional generation (NYSDEC 2008).

It is important to note that on a county-wide basis, the mass of food, yard trimmings, and compostable paper generated from commercial and institutional sources is only 65% of household generation. This means that focusing on improving organic material re-use for households is warranted on the grounds that superior feedstock quantity will allow for more sustainable system expansion. However, both sources of generation provide unique opportunities (and challenges) for sustainable material management.

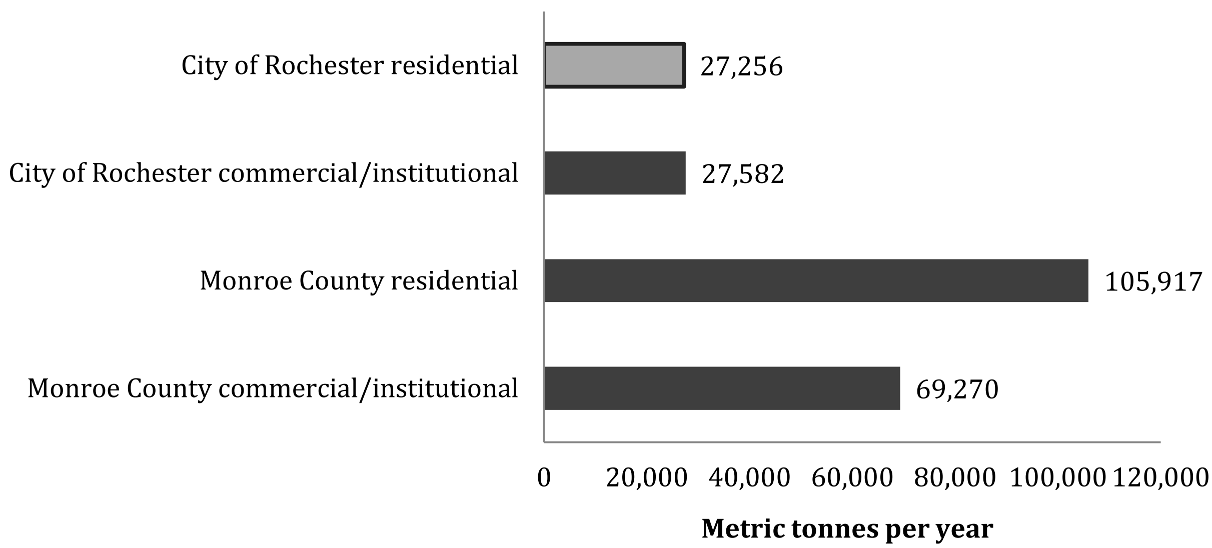


Figure 1.6: Combined food, yard trimming, and compostable paper generation by origin: city of Rochester, NY and Monroe County (NYSDEC 2008)

In the city of Rochester, NY and most places in New York State, household organic material is collected as mixed, non-recyclable garbage destined for a landfill. Currently, about 90% of household organic material flow in Rochester, NY that is suitable for organic waste-to-energy or composting pathways ends up in landfills. This means about 10% of all household organic material that could be used in organic waste-to-energy pathways is diverted from the landfill. Looking at Figure 1.7, we can see that most of this material that is diverted is yard trimmings (such as fall leaves) – which end up being composted. We also see that excess food (1% diversion rate) and compostable paper (<1% diversion rate) are largely unutilized.[1] Food is much more likely to end up in a landfill than yard material; 99% of excess food is landfilled compared to 33% of yard trimmings.

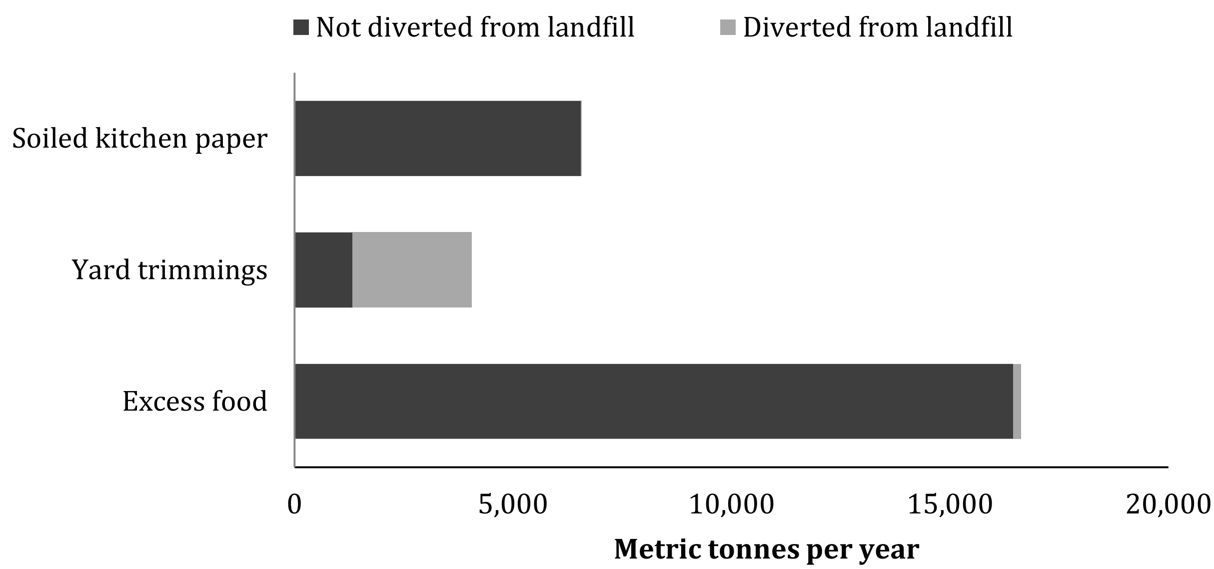


Figure 1.7: Landfill diversion of total excess food (MT/year), yard trimmings, and compostable paper generated from households in Rochester, NY (NYSDEC 2008)

f.2 Projected outlook for waste generation in Rochester, NY

Historically, nation-wide MSW generation grew from 1960 to 2011, at which point it started to steadily decline. Waste generation is a function of population growth, economic activity, and lifestyles (Maine State Planning Office 2010). United States Census data shows that the population of Rochester, NY has steadily declined 4% 1990-2010 (United States Census 2010a). However, over the past two years the population has stayed stable at around 210,500 people. Employment in Rochester, NY has declined at about -0.3% annually since 2003. The number of employed has dropped from about 500,000 to 482,000 from 2003-2013 (Bureau of Labor Statistics 2013). Rochester, NY has made focused investments in education, technology, community, and infrastructure, which will contribute to economic growth in the near future. This is likely to have a stabilizing effect on the population and economic activity. These factors point to the likely event of MSW generation remaining constant for Rochester, NY in the coming years. Thus, at this point in

[1] Calculation based on per capita generation and MSW characterization assumptions from New York State Department of Environmental Conservation (2008).

time, lifestyle changes present a unique opportunity for economic, social, and environmental gains in the city of Rochester, NY.

g. Planning for sustainability in Rochester, NY

g.1 Overview

In Rochester, NY sustainability planning is prioritized by the current Finger Lakes Regional Sustainability Plan. In 2011 the New York State Government established the *Cleaner, Greener New York Program*, which provided nearly $10 million to regional planning areas for the creation of evolving sustainability plans to; "empower regions to create more sustainable communities by funding smart development practices" (Finger Lakes Regional Sustainability Plan 2012). The planning process brought together experts on materials management as one of six stakeholder groups that were developed around New York State Economic Research and Development Authority (NYSERDA) sustainability focus areas. A key implementation step for the plan is to embed the Plan framework into all planning and investment-related decisions (Finger Lakes Regional Sustainability Plan 2012). This research work aims to formulate recommendations for the city of Rochester, NY to more fully address the key challenges and opportunities that were identified in the planning process (Table 1.2).

Table 1.2: Lists of key sustainable material management opportunities and challenges for the Finger Lakes Region of New York State (Finger Lakes Regional Sustainability Plan 2012)

Opportunities	Challenges
• Shift perception from "waste management" to "sustainable materials management" • Energy production for small scale operations and the larger grid • Increased composting, both large and small scale • Change perception of waste to recognize various reuse and recycle outcomes • Collaboration with agricultural and industrial operations	• Reduce lifecycle impacts across the materials supply chain • Lack of local or regional waste tracking systems • Prioritizing investment in reduction, reuse, recycling and composting over disposal • Mitigating impacts of imported waste • Inspiring sustainable choices from households

These opportunities and challenges are being addressed by four broad strategies, each of which is developed in this research:

- Reduce the amount of solid waste generated in the region.
- Increase the percentage of materials reused (upcycled), recycled, and composted within the region.
- Address financial barriers through new revenue and business models.
- Promote comprehensive sustainable materials management education, awareness, and research services.

Local sustainability planning in the City of Rochester is led by the Office of Energy and Sustainability within the Department of Environmental quality (City of Rochester Office of Energy & Sustainability 2014). Where the authority for sustainability planning falls within the municipal organization structure is a reflection of how the City of Rochester conceptualizes sustainability. Practically speaking, the City of Rochester's co-placement of its sustainability and energy offices points to the need for sustainable material management policy strategies that improve the local renewable energy portfolio. More broadly, the placement of sustainability within the Department of Environmental Quality as opposed to Neighborhood and Business Development stresses local government commitment to environmental issues such as pollution prevention. As this research will show, there are profitable means to achieve both of these goals through greater use of anaerobic digestion, SSF, and composting in household organic material management.

g.2 Municipal planning difficulties of sustainable material management

To date, governments have had difficulty designing and implementing policy approaches that positively influence the efforts of citizens to adopt sustainable consumption behavior and lifestyles (Hobson 2003). The shortcomings of existing policy approaches to sustainable materials management are evidenced by the continual upward trend in domestic material consumption, which has increased on a per capita basis by 22% from 1980 to 2005 (OECD 2008). Long-term growth in domestic material consumption has outpaced long-term resource efficiency gains – resource productivity (material use per unit of GDP) has increased by 27% over the same time period. Increased resource use is not synonymous with economic development – resource use does not by definition increase quality of life. Resource use constitutes the material basis of the economy, and simultaneously induces an environmental burden associated with resource extraction and the subsequent material flows and stocks – which finally end up as waste and emissions (Bringezu 2004). Since the environment is the foundation of our interdependent economic engines and social well-being, *decoupling* resource consumption and economic growth is critical to sustainable development. This is primarily accomplished by increasing resource productivity relative to consumption.

As such, the upward trend in domestic material consumption is concerning. It is widely realized that resource consumption will have to *decrease*, or at least stabilize, in order to grow economic well-being for everyone. This is corroborated by the fact that most of the world's resources come from non-renewable sources. Viewing this issue from a systems perspective, what we are observing are natural resource outflows far exceeding inflows. Therefore continued use of non-renewable resources (e.g. fossil fuels, virgin metals) mathematically destined to deplete our existing non-renewable resource stocks, leading to a crippled environmental-economic system (Sterman 2012). Although fossil fuel resources are not likely to run out for up to 100 years by some estimates, existing reserves are becoming more economically and environmentally costly to extract as the *low-hanging fruit* has already been consumed. One possible solution is to consciously switch toward greater deployment of renewable resources. Although this is a necessary step, at present renewables make up a small fraction of total resource use (e.g. 10% of world energy consumption is from renewable sources) (EIA 2014). An undesirable lack of renewable resources highlights the need for smarter use of our non-renewable resources such as fuels (e.g. gasoline and natural gas).

h. Key research objectives

The overarching objectives of this research were to identify a sustainable household organic material management system in the city of Rochester, New York, and explore the environmental, social, and economic performance of system implementation. Achieving this goal required five main investigations: 1) a study of current literature on local organic material management pathways to find environmentally preferable alternatives relative to the incumbent, landfill with gas capture; 2) a determination of potential resident participation in the sustainable management system implementing alternative pathways (i.e. organic material source separation and source reduction behavior, urban agriculture activity); 3) selection of an effective municipal policy to support household organic material processing and incentivize residents to source separate the materials for commercial use; 4) financial impact assessment of the proposed municipal policy change on the budgets of city government and households; 5) a comparison of incumbent and alternative material management pathways for processing organic materials on the grounds of profitability.

For the second objective, that is the determination of potential resident participation in sustainable household organic material management, surveys and interviews were conducted with residents in the Southeast section of the city of Rochester, NY. This sample was selected on the basis of existing environmental networks to aid in distributing the survey, and the current participation of many Southeast residents in sustainable management behaviors. The surveys examined residents' household organic material management behaviors and values, in addition to the financial motives to source separate their organic material for collection. Specific focus areas included: willingness to pay for source separated organic material collection services, current management behavior and collection program participation, awareness and perceptions of organic waste-to-energy systems, urban agriculture, and social capital formation.

For the third and fourth objectives – the selection and assessment of effective policy to support the sustainable system – an initial literature search was performed. It focused on policy frameworks that encourage greater household organic material source reduction, source separation, and commercial collection. Based on the literature of household organic material management policy regimes that are successfully achieving these ends across the globe and the U.S., a weight-based fee for MSW was determined to be preferable for the city of Rochester, NY. The implementation of a weight-based MSW pricing was compared to the current flat-rate fee MSW pricing policy in the city of Rochester, NY via cost-benefit analysis (CBA). The major practical consideration for implementing weight-based MSW pricing was setting the most effective MSW price that would yield gains in household source reduction, organic material source separation, as well as both household and municipal budgets. As such, scenario analysis was performed to find the optimal weight-based fee price to achieve these goals. The outcome of the CBA was a close estimate of the optimal prices for MSW plus total project net present value for the city of Rochester and the average city household.

To accomplish the final objective, an economic comparison of incumbent and alternative household organic material management pathways, a novel Microsoft Excel optimization tool was developed using the What'sBEST add-in. It compared the profitability of four material processing pathways (i.e. anaerobic digestion, SSF, composting, and landfills with gas capture) for managing excess food, yard trimmings, and compostable paper. This model took into account household organic material chemical parameters and expected management pathway revenues and costs for processing. The model pointed to key areas in the organic material management system where the commercial pathways require expansion or process improvement to boost profitability – and thus the likelihood of sustainable implementation. An additional outcome was to estimate the overall private profit that would be earned by processing household organic materials with the most profitable pathways. This last objective was necessary to assist rational investment and planning of the material management system.

Chapter 2: Literature Review

a. Routes of household organic material reuse

There are many dozens of technologically feasible processing pathways that can be used to create higher value products from household organic material. Once access to organic material has been secured for diversion from the landfill, revenue can be generated from biofuels, organic fertilizer, animal feed, and even bioplastics. Although a diversity of technologies may support a more resilient system, decision makers do not have the luxury of developing every single possible method for converting wasted organics into high value products. Rather, the investment of limited funds needs to be optimized in accordance with the technology options that will bring the highest returns. The feasibility and profitability of four specific technologies have been analyzed within the city of Rochester, NY context. They are landfills with gas capture, anaerobic digestion, SSF, and commercial composting. The selection of these four pathways was based on their local advantages as described in sections e.1 through e.4. The following also include in-depth explanations of how the processes work (including diagrams):

The goals of community development are defined by the local community and should leverage existing community assets. A leading framework that describes this process is asset-based community development (ABCD) (Mathie and Cunningham, 2003). Its premise is that community members participate in driving the development process by identifying and mobilizing existing assets, thereby creating and responding to local economic opportunity. A sustainable and effective project will first look to identify and connect assets within the community, and only then look outside to satisfy additional resource needs (Kretzman et al. 2005). Each of the four commercial organic material management pathways has undergone some independent development in the Rochester, NY metropolitan area. As such, they represent existing community assets that can be developed in an ABCD process with community actors. This research seeks to build capacity for local decision-makers involved in the development of a sustainable household organic material management system in Rochester, NY.

a.1 Landfills with gas capture

The status quo for the city of Rochester, NY is landfills with gas capture. Landfills with gas capture are equivalent to landfills without gas capture, except that the methane-containing gases coming off the decomposing organic matter in the landfill are gathered. As Figure 2.1 shows, this landfill gas is used for: 1) electricity production to be used on-site or sent to the power grid; or 2) *flaring* the methane-containing gas by igniting it and keeping an open flame (which has the effect of lowering net greenhouse gas emissions due to the relatively low global warming potential of carbon dioxide compared to methane). Using the landfill is the status quo for household organic material and up-front costs (i.e. tipping fees) are low.

However, landfills with gas capture produce the most emissions compared to the other three pathways and are relatively inefficient in converting organic material to energy. Life cycle assessment studies have found that landfilling material that is rich in energy content (such as food, yard trimmings, and compostable paper) should be avoided as much as possible (Cherubini et al. 2009). This is mainly due to the low recovery efficiency of resources (i.e. biogas for electricity; compost; biofuels) when the material is landfilled (Karagiannidis and Perkoulidis 2009).

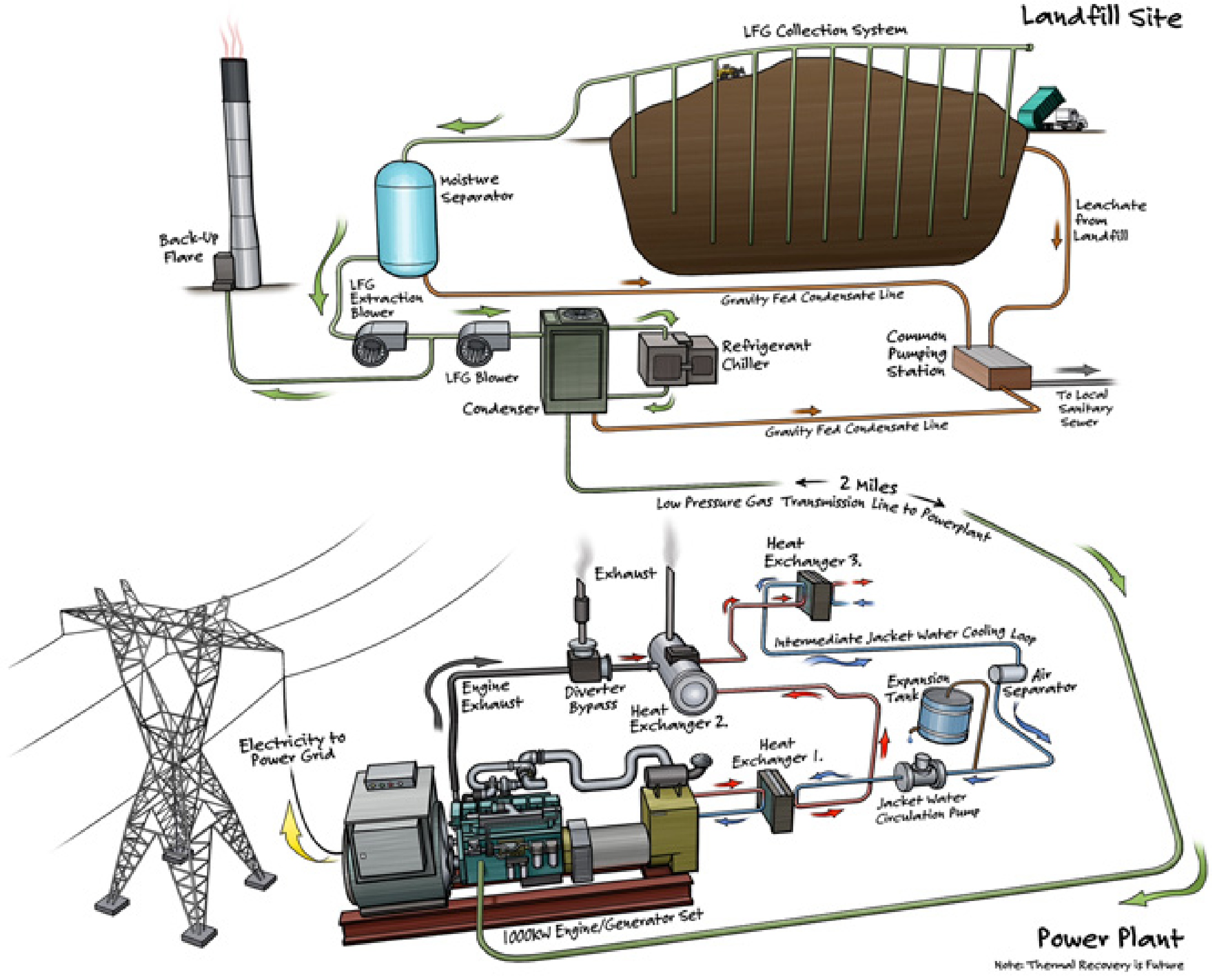


Figure 2.1: A landfill gas to energy system with power grid connectivity (Affiliated Engineers 2013)

In the city of Rochester, NY, two landfills with gas capture are used by the municipal department of environmental services for dumping MSW: High Acres Landfill (on the east side of Monroe County, NY) and Mill Seat Landfill (on the West Side of Monroe County, NY). The performance and set-up of energy-producing facilities at each of the landfills is shown in Table 2.1. It is important to note that the High Acres facility produces gas from the HHOM feedstock more efficiently than Mill Seat, as measured by the ratio of volume landfill gas used for energy over volume MSW produced (ratio of 91 compared to 41). This means that Mill seat produced 41 cubic meters of gas per cubic meter of MSW processed, as opposed to 91 cubic meters of gas per cubic meter of MSW processed at High Acres. Since more efficient gas production results in greater profits (holding tipping fees constant), data from High Acres landfill was used in the pathway profit maximization model in Chapter 5.

Table 2.1: Key data on city of Rochester landfills with gas capture (i.e. Mill Seat and High Acres) for the year 2012 (Waste Management 2013a and 2013b)

Name	Mill Seat Gas-to-energy Facility	High Acres Power Production Plant
Total landfill area	98 acres	205 acres
Landfill gas collection area	90 acres	146 acres
Volume of MSW processed	792,000 cubic meters	574,000 cubic meters
Projected landfill life at current capacity	7 years	39 years
Landfill gas-to-energy production	32,700,000 cubic meters	52,130,000 cubic meters
Landfill gas flared	1,470,000,000 cubic meters	60,740,000 cubic meters
Feedstock to landfill gas energy production efficiency: $\left(\frac{\textbf{Volume landfill gas for energy production}}{\textbf{Volume MSW processed}}\right)$	41	91
Landfill gas plant size	6.4 MW	9.6 MW
Electricity production	54,400 MWH	80,000 MWH
Electricity sold to power grid	52,300 MWH	80,000 MWH

Figure 2.2 shows the location of the landfills in respect to the center of the city of Rochester (as determined by Google Maps) at 217 Saint Paul Street, Rochester, NY 14604. High Acres Landfill is located in Fairport, NY, 16 miles from the center city and Mill Seat landfill is in Bergen, NY, 20 miles from center city.

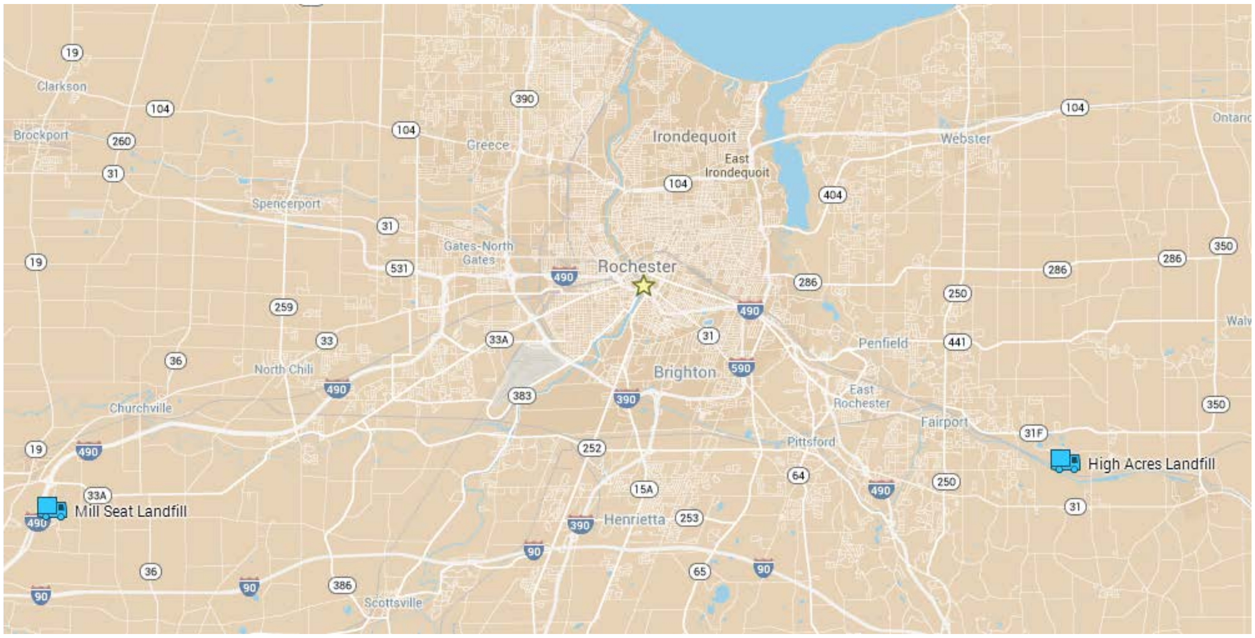


Figure 2.2: Location of city of Rochester landfills (High Acres and Mill Seat) in relation to center city

a.2 Windrow composting

This low-cost practice has been done for centuries in communities and households. Households that engage in home composting reduce organic material generation while enjoying the rich soil amendment for personal or community use. Composting on commercial scales with heavy machinery has become economically preferable due to superior production efficiency. The growing market demand for organic fertilizers has increased the value of compost in recent years.

Successful composting for the city of Rochester, NY is feasible even with limited prior capacity. There are resources (e.g. Master Composter lessons) and consulting (e.g. Commercial Agriculture Program) available to assist new commercial composters through Cornell Cooperative Education Center of Monroe County. In addition, there are existing commercial composting companies located in and around the city (e.g. Community Composting, Rochester, NY; Worm Power, Avon, NY; Vermicycle, Hamlin, NY). Entrepreneurial opportunities exist for additional compost production *within* city limits. There appears to be latent demand for compost, as the Rochester City garden permit requires that garden plots on city land utilize raised beds consisting of amended soil (City of Rochester, NY 2014a). This soil is almost exclusively imported outside the city limits, due to contamination of city soil and lack of local compost producers. In the city of

Rochester, NY, only the Community Composting enterprise is creating compost using residents' source separated organic material. This unique company currently hauls organic material from households to a windrow composting facility (Vermi-Green LLC, in Palmyra, NY) in return for a monthly subscription fee and a bucket of finished compost (Community Composting 2014). The Community Composting business is discussed in depth in Chapter 2, section b.4 and again in Chapter 3, section b.2.

Windrow composting was analyzed in this research because it is the most commonly used commercial composting process, and because it creates a quality product without electricity (Penn State Extension 2014). It involves using a machine to turn the piles of organic material – a necessary step to ensure that compost remains uniformly mixed (see Figure 2.3 for an example). This is important to ensure proper proportions of air and water, as well as a stable carbon to nitrogen ratio (Richard and Trautmann 1996).

Composting is most efficient when the feedstock has an elemental ratio of carbon to nitrogen that is between 20:1 and 30:1 (Richard and Trautmann 1996). If there is too much carbon (i.e. the ratio is too high) the aerobic bacteria that break down the material will not have enough nitrogen, an essential nutrient for cellular growth (Richard and Trautmann 1996). On the other hand, if there is too much nitrogen (i.e. the ratio is too low) the aerobic bacteria will be short of the energy-rich carbon that provides food for new cells (City of Euless 2013; Richard and Trautmann 2014). In either case of imbalance, composting occurs very slowly. Household organic material feedstocks vary in C:N from 10:1 (some foods) to 150:1 (dry yard trimmings) (Rynk 1992). As such, it is necessary for composters to access a mix of feedstocks to enable efficient compost production at an optimal C:N.

In addition, moisture content is maintained at certain levels using moisture monitors to create a healthy environment for aerobic composting bacteria. If percent moisture is too high (greater than 50%) the air pores in the substrate fill with water and promote anaerobic conditions by crowding out oxygen. At levels lower than 50%, the aerobic bacteria will not have enough water for optimal growth and organic material decomposition (Richard and Trautmann 1996).

Figure 2.3: A windrow composting system with turner machine (BioCycle 2012)

a.3 Anaerobic digestion

An anaerobic digester converts organic material into biogas and compost by utilizing bacteria that flourish in the absence of oxygen. In many parts of the world anaerobic digestion has been used for municipal and agricultural applications on community scales for over a century (T. Abbasi et al., 2012). The use of AD is institutionalized and widespread in many European nations and is used in both rural and municipal settings. Figure 2.4 shows a farm-based digester as part of an integrated organic material (e.g. manure) management system. It is profitable for farm-based digesters to accept food waste materials from outside the local community to take advantage of co-digestion – i.e. mixing in other organic substrates to the process (Rankin 2013a). Anaerobic digesters operating on manure achieve higher overall feedstock biomethane potential (quantified in mL CH_4/g volatile solids) by co-digesting organic materials such as excess food and compostable paper (as empirical results show in Chapter 5). As such, there are potential growth opportunities to gain from closer ties between urban and rural organic material management systems via collaboration with the anaerobic digestion pathway.

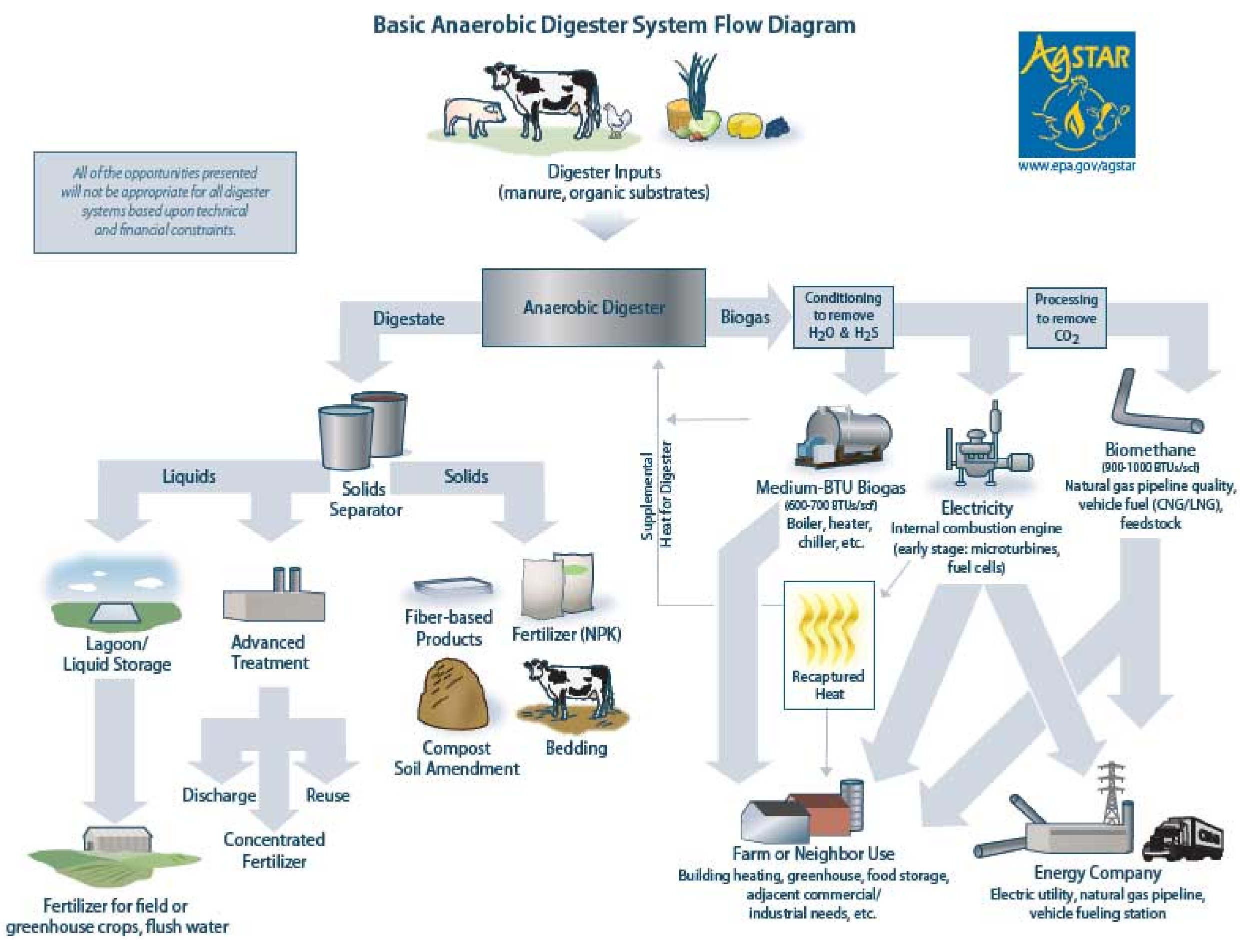


Figure 2.4: Flow-chart of anaerobic digestion system with municipal and agricultural feedstocks (EPA AgStar 2014)

The right side of Figure 2.4 shows how biogas is scrubbed of hydrogen sulfide before being used in an electric generator for on-site consumption or as a feed-in to the power-grid. Material that is not converted to biomethane by anaerobic digestion (AD) is called the digestate. This material can be converted to compost soil amendment (Figure 2.4). The microbially active compost co-product can be profitably used in agriculture because it promotes healthy soil ecosystems. Using compost contributes to energy and GHG savings from reduced tillage, irrigation, fertilizers, and pesticides, in addition to regulating soil fertility that is essential for good crop yields (Mondini et al. 2008).

Urban anaerobic digestion of source separated organic material

Anaerobic digesters are flexible organic material management pathways because they can operate in both urban and rural communities. An urban example is the system at The Plant in Chicago, IL (Figure 2.5), which is a net-zero energy multi-use space in the heart of Chicago's economically depressed Back of the Yard neighborhood. The space is operated by The Plant, a not-for profit (NFP) business that operates the building with for-profit business tenants (such as vegetable and fish farmers, tea and beer breweries, and kitchen incubators). This type of arrangement is known as a social enterprise model, where social, environmental, and profit-driven goals are pursued simultaneously through a non-profit/for-profit partnership (The Plant 2014a). The Plant, NFP is charged with promoting the closed-loop system in the production facility through research, education, and business development.

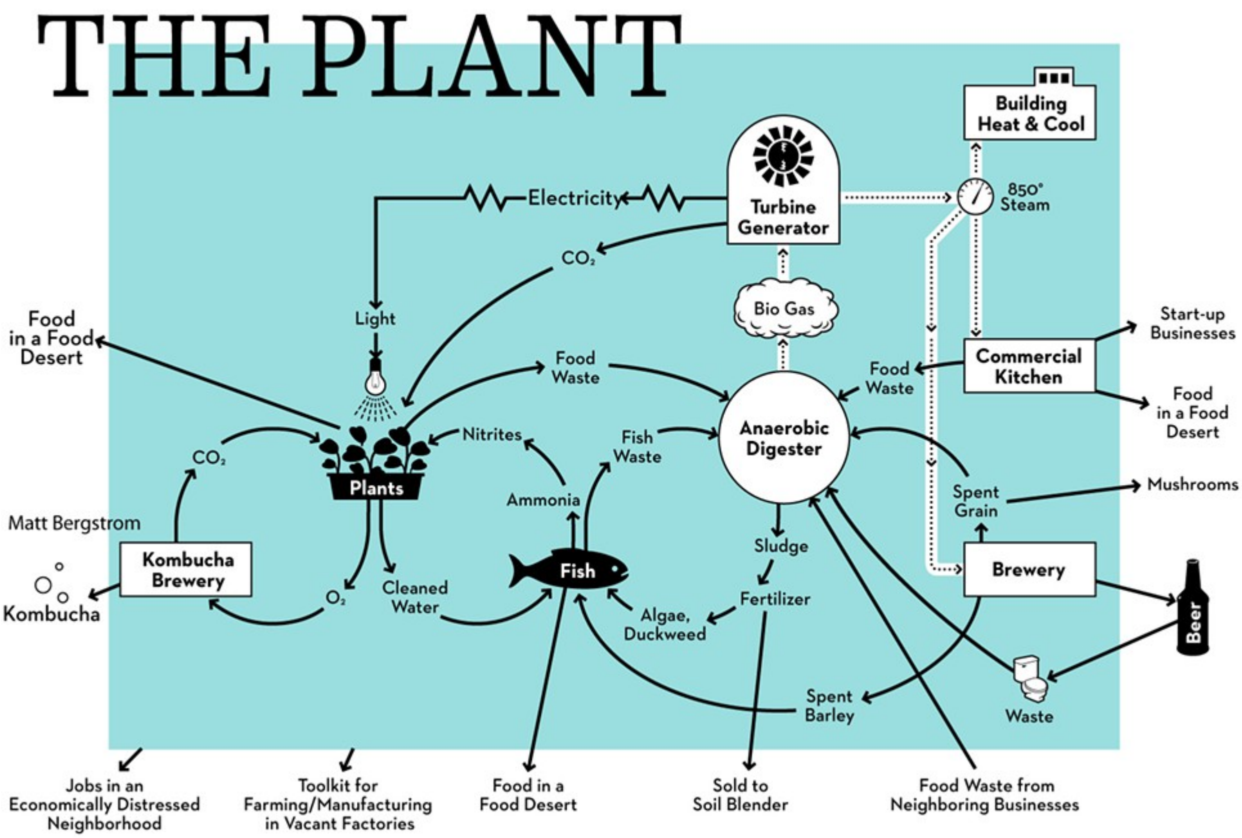


Figure 2.5: Flow diagram of urban anaerobic digester at The Plant, Chicago, IL, a food production operation, business incubator, and community space located in a repurposed warehouse (Bergstrom, 2011)

Thus far, The Plant has succeeded in attracting long-term tenants to its shared building, primarily from the food industry. The Plant has offered tenant spaces at low rent and low, predictable energy costs due to onsite electricity generation via anaerobic digestion. (The Plant 2014b). As Table 2.2 shows, considerable energy is generated at The Plant, in addition to compost material and liquid fertilizer outputs that are utilized in the local community (Eisenmann 2014). Biogas production at The Plant anaerobic digester is aided by incoming organic (waste) material from the surrounding neighborhood (e.g. excess food from food processors), which has resulted in over 5,000 tons of diverted organic material in the first year of operation (Eisenmann 2014).

Table 2.2: Eisenmann biogas key data at The Plant anaerobic digester, Chicago, IL (Eisenmann 2014; The Plant 2014a)

Parameter	Description
Production start date	January, 2013
Overall building footprint	80 ft. x 170 ft.
Organic material (waste) input	5,000 short tons/year
Rate of biogas energy production	2,320 megajoules/hr
Electricity production	200 kWh/hr
Composting material output	1 ton/day
Liquid fertilizer output	8 tons/day
Digester capital cost	$2,100,000

Overview: the biochemical process of Anaerobic Digestion

From a biochemical perspective, the processing of organic material in an anaerobic digester occurs in four main steps, as displayed in Figure 2.6. Hydrolysis is the first step, where complex polymeric organic matter is broken down into simpler, soluble components (Al Seadi et al. 2008). Next is acidogenesis, where the products of hydrolysis are converted by acidogenic (fermentative) bacteria into acetate, volatile fatty acids, alcohols, carbon dioxide, and hydrogen. In the third step – acetogenesis – volatile fatty acids and alcohols from acidogenesis are converted to the methanogenic substrates (i.e. acetic acid, hydrogen, and carbon dioxide). In the final step, methanogenic bacteria produce methane and carbon dioxide from the methanogenic substrates. About 70% of the formed methane originates from acetate, while the remaining 30% is produced from conversion of hydrogen and carbon dioxide. The rate of methanogenesis is strongly influenced by operation conditions and composition of feedstock (Al Seadi et al. 2008). For this reason, empirical data on biomethane yield was collected in this research to accurately model the profits that could be achieved by anaerobic digestion of household organic material feedstocks in Rochester, NY.

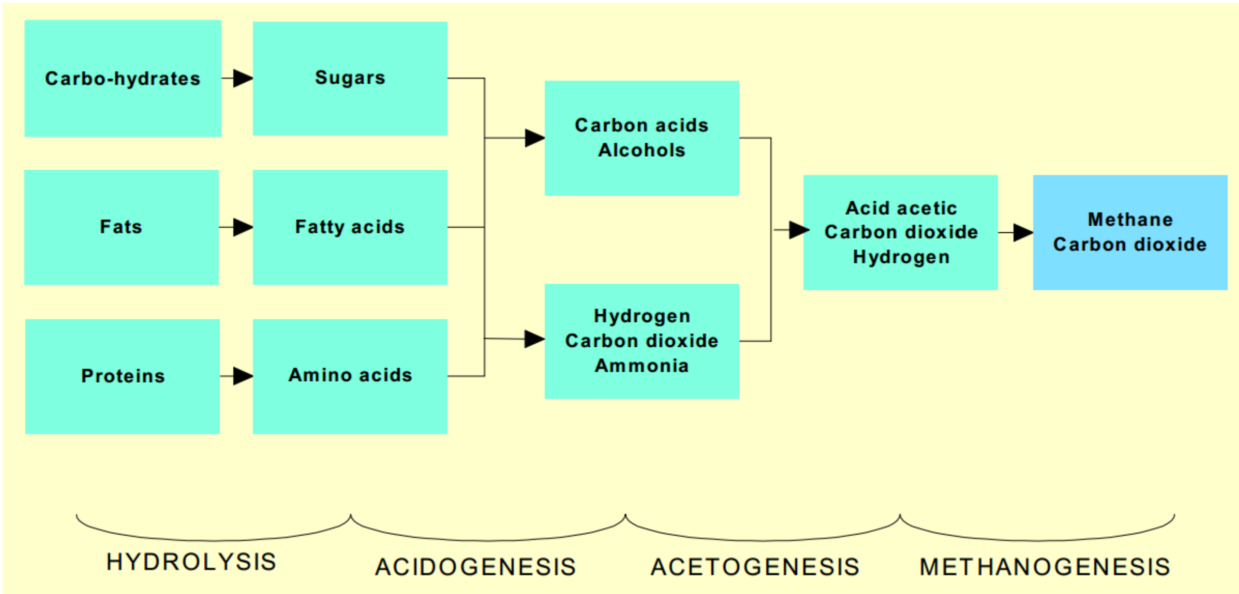


Figure 2.6: The four main biochemical steps in anaerobic digestion (Al Seadi et al. 2008)

Local anaerobic digestion: Rochester, NY

In Rochester, NY, AD has been used by at least five different food waste generators by sending the material to an anaerobic digester managed by a cooperative of dairy farmers in Covington, NY (Rankin 2013a). The facility is shown in Figure 2.7. The anaerobic digester is economically beneficial to Rochester, NY food waste generators because the AD tipping fees ($0.01/kg) (Rankin 2013a; Forster-Carneiro et al. 2008) are lower than the landfill ($0.07/kg) (Waste Management 2013c). As such, there is an incentive to ship the material up to 45 miles to the facility (Rankin 2013a). The economic benefits to the farm AD operators come from revenue generated by electricity added to the grid, and by the tipping fees charged to food waste generators. In addition, residual solids suspended in the produced liquid from the digester (digestate) can be turned into animal bedding for on-site use, or sold as compost.

Figure 2.7: Synergy Biogas, LLC farm-based anaerobic digester in Covington, NY (CH4 Biogas 2011)

a.4 Simultaneous saccharification and fermentation

Simultaneous saccharification and fermentation (SSF) is a proven technology for converting organic materials into ethanol, compost, and animal feed products. This process is also referred to as cellulosic ethanol fermentation – meaning that it can utilize organic materials (e.g. cellulose) that are normally unsuitable for fermentation. SSF is a 2nd generation biofuel process, meaning that it does not require feedstocks that compete with food crops. Conventional ethanol is normally produced from corn, which indirectly drives up food and fuel prices. Even dedicating all U.S. corn and soybean production to biofuels would meet only 12% of gasoline demand and 6% of diesel demand (Hill et al. 2006). SSF or cellulosic ethanol production utilizes wasted organic material such as that found in households. Transportation biofuels such as cellulosic ethanol produced from waste biomass could provide much greater supplies and environmental benefits than food-based biofuels (Hill et al. 2006).

The development of SSF is compatible with sustainable development principles. First, it does not worsen the effects of poverty. Corn ethanol consumes scarce food supplies, negatively impacting the 60% of the global population facing malnourishment (Pimentel et al. 2008). Secondly, it increases resource productivity compared to conventional ethanol production, given its smaller ecological footprint per dollar of value-added products produced. As previously mentioned, Ebner et al. (2014) found that ethanol from a local SSF process presents a 554% improvement in GHG impacts relative to corn ethanol and 460% relative to conventional gasoline. Even without the inclusion of avoided landfill impacts, the process emissions compare favorably to other ethanol production technologies.

Expanding SSF ethanol production makes good economic sense, as the market demand for fuel-grade ethanol is on a long-term upward trend. The federal government's renewable fuel standard enacted in the Energy Independence and Security Act of 2007 increased the volume of renewable fuel required to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022. In addition, future global targets and investment plans suggest growth of biofuel ethanol will continue in the near future, rising to around 27 billion gallons in 2014, 45% more than produced in 2008 (IEA, 2009)

Overview: fermentation (SSF) process

As we can see in Figure 2.8, the local SSF process takes in organic material source separated from the municipal solid waste stream at the staging area. From there, mechanical pre-treatment (grinding) and chemical pre-treatment (usually with dilute sulfuric acid) take place to create a slurry of biomass with more simple sugars. The hydrolysis step further breaks down the biomass using an enzymatic process converting remaining polymeric sugars into simple sugars. Simultaneously, fermentation is occurring, which is a series of chemical reactions caused by yeast or bacteria that feed on simple sugars. As the sugars are consumed, ethanol and carbon dioxide are produced. The remaining by-products are further processed to make food-grade animal feed (also fit for human consumption) and compost soil amendment. A small amount of water-based waste product is also produced. As the lower half of Figure 2.8 shows, the dilute ethanol solution (called distiller's beer) from the local SSF facility can then be processed in a regional ethanol biorefinery. The drop-in biofuel precursor is used in place of corn-derived distiller's beer, thereby avoiding the resource use of a corn fermentation process (shown outside of the red brackets in Figure 2.8).

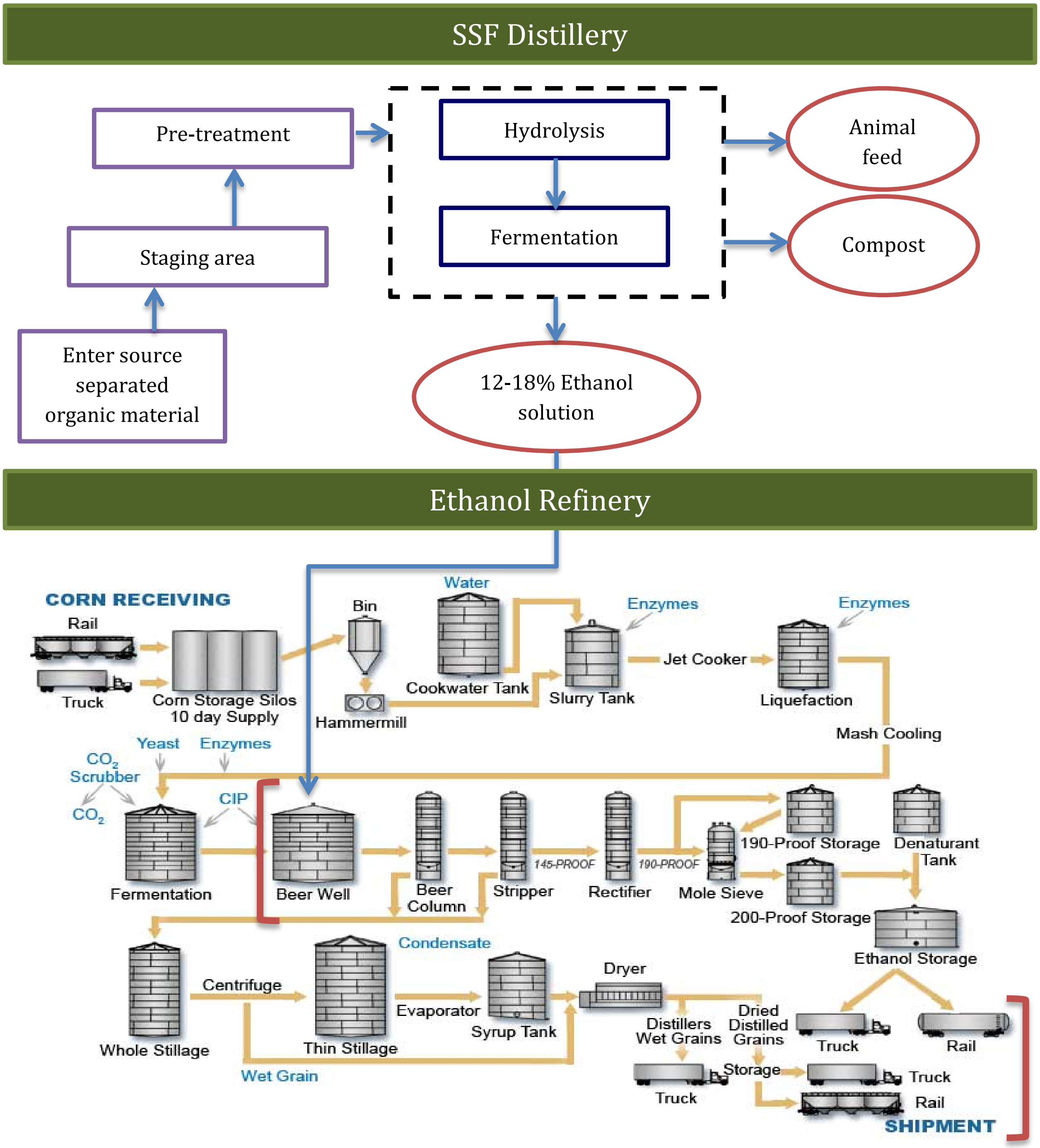


Figure 2.8: Process diagram of a local simultaneous saccharification and fermentation process

b. Survey development: economic and normative motivations for sustainable organic material management

A critical component of this research included the development of a survey to inquire about the sustainable management behaviors and motivations of city residents who would be likely to participate in a pilot program for collection of source separated household organic material. Residents of the Southeast section of the city of Rochester, NY were targeted primarily due to their strong existing citizen sustainability networks to help disseminate the survey (e.g. Zero Waste, Sierra Club), and a relatively high level of activity around organic material management (e.g. many Community Composting subscribers, numerous environmental community groups). The survey in Chapter 3 of this research focuses at the resident level to increase citizen engagement in the material management system. Only inclusive policy secures marked changes in consumption and material management practices (Burgess et al. 1998).

The survey purpose was to get community-level feedback on how expanded organic material re-use in AD, SSF, and composting pathways could effectively improve local resilience. Community resilience is defined as "the existence, development, and engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability, and surprise" (Magis 2010). Community resilience is a hallmark of sustainable systems (Magis 2010), and is a desirable outcome of sustainable organic material management practices. In the Finger Lakes Region where the city of Rochester, NY is located, there is strong emphasis on resilience as it relates to: 1) maintaining the health of the agricultural sector and 2) improving communities with high rates of poverty and food insecurity (Finger Lakes Regional Sustainability Plan 2012).

Mounting evidence from diverse regions of the world supports the concept of community resilience. Research shows that natural and socio-economic systems are complex and evolving, exhibit marked thresholds in their dynamics, and act as strongly integrated units (Folke et al. 2002). Connections between resilience and organic material management are highlighted by applying principles of *industrial ecology*. This scientific field is the study of the physical, chemical, and biological interactions and interrelationships both within and between industrial and ecological systems. A fundamental tenet of industrial ecology is that industrial systems are often analogous to ecological ecosystems in how they function.

Not surprisingly, the concept of community resilience was first conceived of by ecologists (Holling, 1973; Pimm, 1984). Early observers of community resilience such as Holling pointed out that disturbance of renewable natural resources such as plants and animals (i.e. harvest) will result in population instability. Depending on the size of the perturbation, the natural resource population/reserve can flip into a state of erosion (and eventually collapse) – even after extended periods of high yields. Once the tipping point is reached, the speed of replenishment can be reduced so much that yields will continue to be very small for a long time. Meanwhile, communities that depend on those resources are vulnerable to damage, or depending on the level of dependency on the resource, failure. A resilient society should aim to assure a stable maximum sustained yield that can, "absorb and accommodate future events in whatever unexpected form they take" (Holling 1973). In the context of the city of Rochester, sustainable yield relates to economic productivity and job growth in the face of economic volatility and uncertainty without reducing social or environmental health in the community. As the next section outlines, there are multiple aspects of organic material management that enable community resilience.

b.1 Exploring local links between sustainability, organic material management and local agriculture

Recognition of the synergies between social objectives (e.g. building social connections, food security, providing work for disadvantaged people) and sustainable resource management could enable the development of organic material re-use pathways (Lane and Watson 2011). The survey in Chapter 3 was designed to explore these synergies in Rochester, NY by asking residents about their current participation in food production, as well as their current interactions with their neighbors.

Resident food production was a focus of the survey since productive agriculture is strongly tied to soil health. Soil is a renewable natural resource that behaves similarly to how Holling and Pimm described in their studies of ecological resilience. Thus, over-consumption and disposal of household organic materials (especially food) is very taxing on them. In addition, there is increasing global and local need for "sustainable intensification" of the food system by increasing output and efficiency while reducing waste and environmental impacts (Godfray et al. 2010).

The status quo of landfilling post-consumer organic material means that virtually none of what is taken out of local and global soil resource stocks is directly replaced. Without replenishment with soil amendments (i.e. compost), the system moves toward a tipping point – likely either a sharp collapse in productivity or steep increase in demand for additional resources to support the system. These resources such as synthetic fertilizers have environmental impacts of their own, due to fuel consumption required to produce them. As discussed earlier, sustainable organic material management utilizes feasible re-use pathways such as AD, SSF, and commercial composting to produce compost and fuels which bolster natural resource stocks to the benefit of local agriculture and sector resilience.

Unfortunately, the environmental impacts of agricultural practices (such as resource depletion) are largely unmeasured and often do not influence societal choices about production methods (Tilman et al. 2002). New policies to ensure the sustainability of agriculture will be crucial if we are to meet the demands of improving yields without sacrificing public health and sector resilience. The local resilience benefits of AD, SSF, and composting is the primary motivation for studying Rochester, NY resident's organic material management behaviors and values. The survey explored social sustainability aspects by asking residents about their likelihood to participate in programs that enable re-use pathways as well as their willingness to purchase the locally produced energy and compost.

An additional synergy between organic material management and social objectives is explored by Sundkvist et al. (2001), Curtis (2003), Jansson (2013), Colding and Barthel (2013) and others. They articulate that there is much promise in policy approaches that incentivize and empower individuals to redirect their consumption patterns to local options. For example, by adopting increasingly local consumption patterns, communities increase the positive externalities of self-reliance (e.g. independence in decision-making) and decrease the negative externalities of long-distance trade (e.g. transportation emissions). Examining these externalities of consumption has led to a re-conceptualization of how production scale and production efficiency can be decoupled when a strong local community is a goal (Curtis 2003). In short, bigger is not always better for local environmental-economic systems. Organic material management is well-suited to leverage the efficiency of regional and community-scale operations because of the strong connection between management pathways co-products (e.g. fertilizer, fuel, and feed) and Upstate New York's economic backbone – the agricultural economy.

In the Rochester, NY area, many local farms have been lost over the years to development and struggling markets, yet there remain dozens of family farms that are the backbones of their communities. It has been shown that increasing participation in local food production bolsters social sustainability indicators such as health, food security, and poverty that are areas of focus for the city of Rochester, NY. For example, gardening has been shown to yield physical exercise, stress release, increase in cardiovascular health, and lower overall risk of mortality (Brown and Jameton 2000; Ekblom-Bak et al. 2014). Additionally, agricultural participation is an effective way to correct misperceptions regarding the nutritional value of food – thus making it policy that can change poor food choices that contribute to obesity (Lautenschlager and Smith 2007).

Local agriculture improves resilience by building supportive neighborhood connections and social capital (Brown and Jameton 2000). Social capital is correlated with economic prosperity and with relative social equality (Putnam 1993; 2000). Public participation is required to sustain the local systems upon which we all depend, and is especially important for disenfranchised residents that suffer from lack of equity in political and economic decision-making (American Planning Association 2000). Additionally, local agriculture addresses poverty alleviation in Rochester, NY. A local example is the Children's Garden at First Street in the Marketview Heights neighborhood, which has helped improve crime trends (City of Rochester, NY 2013b), youth education, resident engagement, and food security since its inception in 2009. Food production allows urban consumers to achieve higher rates of food security – particularly in areas lacking healthy food access – and enable greater sustainability and resilience in urban ecological-economic systems (Barthel and Isendahl 2013). Local food production is a relatively accessible industry, especially for low-income entrepreneurs (Brown and Jameton 2000). Access to high quality local compost at reasonable prices enables agriculture by reducing a major fixed cost.

Local agriculture is compatible with an assets-based community development approach because it recognizes opportunities where others see community problems (Kretzman and McKnight 1993; Mathie and Cunningham 2003). Land is normally another barrier to urban agriculture, but the city of Rochester, NY has high land vacancy rates. Although vacancy is normally viewed as a negative, it is an asset to community agriculture when used in combination with organic material management products. The city of Rochester, NY Project Green strategic demolition program consolidates vacant parcel demolition to create hundreds of acres of central green spaces, urban forest areas, community gardens and new development possibilities for private urban agriculture businesses (City of Rochester, NY 2009). Over the next twenty years, it will only increase demand for local assets created from organic material management.

In addition, local agriculture participation is an example of sustainable consumption behavior. Many of the benefits of community gardens are non-rival goods (e.g. viewing a beautiful place, conversing with neighbors, enjoying a crime-free/secure environment) which means that for the marginal cost of providing the good for an additional consumer is zero. As Wagner noted in his 2006 paper "On the economics of sustainability" increasing the consumption of non-rival goods is a necessary component for sustainably reducing resource use while maintaining quality of life.

b.2 Household motivations, values and organic material management

Raising awareness of sustainable practices has received attention from municipalities as a primary tool to influence sustainable household behaviors (Gibson et al. 2011). The literature suggests that effective policy to promote sustainable resource management connects government actions with the motivations of households (Shove 2003; Gibson et al. 2011; Hawkins 2006; Nyborg et al. 2006). Household motivations to act are directly informed by values and awareness (in addition to economic criteria). Therefore, the survey of residents in the Southeast section of the city of Rochester, NY in Chapter 3 took a general look at awareness of sustainable organic material management practices.

"Green" households appear to accept individual responsibility for the provision of public goods (e.g. reduced emissions, growth of local business). Perceptions of their community impacts are informed by complex, cross-cutting values: a sense of social justice; of doing right by one's family, neighbors, and friends; by how best to raise and educate children; and also by norms of cleanliness, comfort, convenience and waste (Shove 2003, Hawkins 2006). As such, survey participants were asked how conscious they are of the impacts of their household organic material management practices, and were also asked about the benefits they derive from managing organic material in their chosen way.

The propensity to take responsibility for sustainable behavior may depend on beliefs about others' behavior, even for consumers motivated by internalized moral norms. Households are not detached units but rather situated in contexts that guide normative behavior (Gibson et al. 2011). Work by Nyborg et al. (2006) suggested that; "permanent increases in green consumption may be achieved by imposing temporary taxes or subsidies, or through advertising that influences beliefs about others' behavior or about external effects." Environmental values were a focus of the survey to find out if the residents really do care about the environment – information which could be used to influence others to behave sustainably.

b.3 Incentivizing sustainable household organic material management

The weakness of policy seeking to motivate sustainable behavior purely through environmental education is the assumption that information alone prompts individuals to adopt sustainable lifestyles. Given the lack of causality between sustainable values and actions (Hobson 2003, Davison 2008), sustainable development policy has been largely ineffectual in high-income countries like the United States (United Nations Conference on Environment and Development, 1992). Why might education be ineffective as a stand-alone policy? One explanation is that households simply do not have the time to undertake the required 'thinking work' around sustainability (Gibson et al. 2011; Tanner and Kast 2003). However, this does not suggest any immediate solutions. Work by Vining and Ebreo (1990) found that among those who were not participating in material recycling programs, financial incentives to recycle were particularly important. Thus, in order to increase sustainable behavior among those not currently engaged in a sustainable material management system, financial incentive is the key. As such, the Southeast Rochester resident survey in this research gauged the extent of residents' financial motivations to participate in household organic material management through source separation and collection.

In relation to opportunity costs, one question that needs to be answered is "how easy is it to adopt green practices?" Scholars have found that being green may not in fact be so easy or its choices self-evident (Gibson et al. 2011). The preponderance of research by environmental economists has connected "green" behaviors to materialistic motives (e.g. costs of certain actions, social status). The survey in this research was designed to find out how opportunity costs influenced current and potential organic material management behaviors of residents in Southeast Rochester, NY. However, lasting changes to individual behavior require effective incentive structures in both financial (economic) and normative (social/environmental) areas. Awareness of the environmental and social impacts of resident behaviors was of interest because these beliefs influence moral motivations to participate in household material source separation and collection.

Although values do not determine behavior, they do directly impact residents' perceived costs of participation. Moral motives (e.g. pro-sustainability) significantly lower the perceived household costs associated with household recycling efforts (Berglund, C. 2006), thereby raising participation rates. Berglund (2006) determined this by comparing the average hourly willingness to pay to let others source separate their household material with residents' corresponding wage (i.e., the opportunity cost of time). The result was that the average hourly willingness to pay to let others source separate materials from household MSW was significantly lower than residents' monetary value of the time to perform the task on their own. This finding points to the conclusion that in the absence of moral motivations (that lower the perceived opportunity costs of source separation), financial incentives are necessary to encourage and sustain participation.

It is necessary to establish a household material management system that facilitates residents' ability to carry out their good intentions. Motivation (i.e. values and economic incentives), abilities (i.e. education) and opportunities (i.e. physical conditions for participation) are the three key areas where this can be achieved (Thøgersen 1994). According to the model of resident recycling behavior in Thøgersen (1994), information is indeed an important instrument for affecting motivation for source separation. But, when the goal is to change resident behavior, managing the physical conditions for participation are as important as information management (Thøgersen 1994). Two examples of important physical conditions for participation are weighing-machines that enable weight-based fees for MSW collection, and the availability of curbside collection service for source separated household organic material. Without these conditions in place, residents will have difficulty participating even if motivation and ability are there.

b.4 Private-public partnerships and sustainable material management

Community Composting, LLC opened for business in the spring of 2013 in Rochester, NY (Moule, J. 2013). Community Composting (CC) began with 300 volunteer subscribers in the community without any direct support from the City of Rochester. CC can be considered a social enterprise that has parallel goals of environmental protection via landfill reduction and making profit. The business helps address the physical barriers to resident participation in sustainable household material management. It is doing so by performing a much needed service: facilitating the collection of valuable household organic material.

The core business activity of Community Composting is to haul buckets of household organic material from subscribing households to a local compost producer (Figure 2.9). Each week the firm returns a clean collection bucket to the household. Once each month, compost produced from their HHOM is delivered during weekly organic material collection. Alternatively, subscribers may opt to have the compost donated to a local community garden. A third route is to get a live potted herb planted from regional growers. CC is a growing enterprise in the city of Rochester that has utilized local SSF and composting pathways to re-use household organic material. In the past, CC has utilized a local SSF process (described in Ebner et al. 2014) for compost and currently use a local windrow composting process (Community Composting 2014).

Figure 2.9: Source separated household organic material being processed by Community Composting (Community Composting 2014)

Community Composting participants were a population of interest for the resident survey in Chapter 3, since they are already participating in a household source-separation program. CC respondents were given an extra set of questions at the end of the survey that asked about program satisfaction, benefits and costs of participation, and interaction with neighbors. The CC responses were compared to city residents who were not CC subscribers that had elected to take the survey based on their interest in household organic material management.

Lane and Watson (2011) identified a need for research on social enterprises such as this, given that social enterprises tend to be more innovative initiatives for sustainable resource management than those coming from government. They hold that studies of social enterprise;

> "[…] Would advance understanding of the tensions entailed in balancing multiple objectives and help identify opportunities for greater synergies between policy and practice in different areas of government. In particular, they may offer insights into the issues associated with scaling up initiatives arising from charity, business or government sectors."

The literature suggests that public-private partnerships such as this are necessary for expansion of material re-use pathways. This was corroborated by Lane and Watson's (2011) study of textile material re-use in Australia, where they identified a role for both formal (i.e. centralized government or business institutions) and informal (i.e. non-centralized citizen associations) organizations. When analogous curbside recycling initiatives began in the 1970s they were initially driven by environmentally conscious individuals and community organizations. Government support through policy (e.g. subsidy) allowed start-up recycling companies to scale up to large-scale commercial operations, such that material recycling is under the domain of multinational companies (Koponen 2002).

c. Household organic material management policy selection

c.1 Overview

Chapter 4 of this research was intended to estimate the financial impacts of policy changes that would enhance sustainable organic material management using a cost-benefit analysis. To do so, a framework was needed with a policy goal, and a clear policy lever hypothesized to achieve the goal. The next four sub-sections of this literature review 1) confirm clear policy goals that organic material management policy can address to improve sustainability, namely better household organic material source reduction and source separation; 2) identify the pros and cons of landfill taxes/bans to achieve the goals; 3) identify the pros and cons of a pay-as-you-throw weight-based pricing policy on MSW to achieve the goals; 4) examine pay-as-you-throw implementation by comparing pricing schemes in the US and Europe.

c.2 The case for source reduction and source separation

Prevention of food losses enhanced by separate collection has been shown to considerably reduce GHG emissions. Food loss reduction activities that reduce leftovers or food expiration have a relatively large GHG reduction impact as a waste management strategy (Matsuda 2012). A study by Matsuda (2012) found that a 1% decrease in the amount of edible food disposed of had the same GHG-reduction effect as a 31% increase in the food waste separation rate – even when incineration was the default management practice and the separated food waste went to anaerobic digestion.

Studies have shown that participation in source-separation of food leads to households having greater awareness of their wasteful food practices, thereby encouraging food loss prevention (Su et al. 2010). This means that there is a double environmental benefit from diverting household organic materials to alternative pathways that rely on source-separation policy for feedstock access. Alternative pathways such as AD, SSF, and composting are environmentally superior to landfills on their own, and source separation increases food loss prevention practices.

One of the important issues in household organic recycling is the separation of organic material from non-organic material which would normally end up in the municipal solid waste (MSW) stream. Curbside collection of household organics appears to be a viable opportunity for organic material recovery, as 85% of Northeast households are already served by curbside collection programs (Environmental Protection Agency 2011). Since this is the cultural norm, a curbside collection program was used in this study. It is likely to be the most efficiently implemented by existing stakeholders and readily accepted by residents – thus leading to higher participation rates. To test this hypothesis, the resident survey asked residents about their collection preferences – either curbside collection or community drop-off points.

San Francisco was the first major U.S. city to mandate curbside collection of household organic material, but it is no longer the only one. There are now more than 90 cities with such programs, including Portland and Salem, OR; Boulder, CO; and Seattle, WA. Most of these programs were initially motivated by lack of landfill space – an issue which does not exist in the Rochester, NY area. However, landfill tipping fees are still an expense which can be largely avoided – by diverting organic material in addition to materials like glass, cardboard, and aluminum, the city diverts 78% of its waste from landfills. Additionally, many municipalities (e.g. Portland, OR) have been able to save on hauling costs by changing weekly garbage collection to bi-weekly. Customers just weren't producing as much trash, while weekly separate organic collection ensured that foul odors were not a concern (Daigneu 2012).

There are two general ways to separate the material for organic recycling: 1) source separation, where material is separated by households and 2) mechanical separation, where material is separated by machine. Household source separation is used as the baseline in this research for a three reasons:

- **From a climate perspective, source separation is favorable to mechanical separation** as the machines use a significant amount of energy to separate the organic material, which erodes GHG savings relative to source separation (Matsuda 2012).

- **If MSW is not separated at source, considerable pre-processing is required** to remove plastics, metals, glass, and any other objects not suitable for AD, SSF, and composting (Ward 2008).
- **Source separation is associated with high municipal material recovery levels.** A report by the European Environment Agency (EEA) which tracked material recovery indicators and performance from EU member states over the past two decades verified the efficacy of mandatory separate collection schemes. The EEA found that once countries have set up separate collection schemes for at least paper, metal, plastic and glass by 2015, (as required by Article 11 of the 2008 Waste Framework Directive) the recycling rates can be expected to grow significantly in many countries (European Environment Agency 2013a). As Figure 2.10 shows, roughly over the past decade Europe has made progress in the number of countries attaining higher recovery fractions of materials (including organics) in municipal solid waste. However, research has shown that mandatory participation does not have clear positive impacts on resource recovery rates, even when strong enforcement measures (and thus overhead costs) are in place (Miranda and Aldy 1998; Goldin 1987).

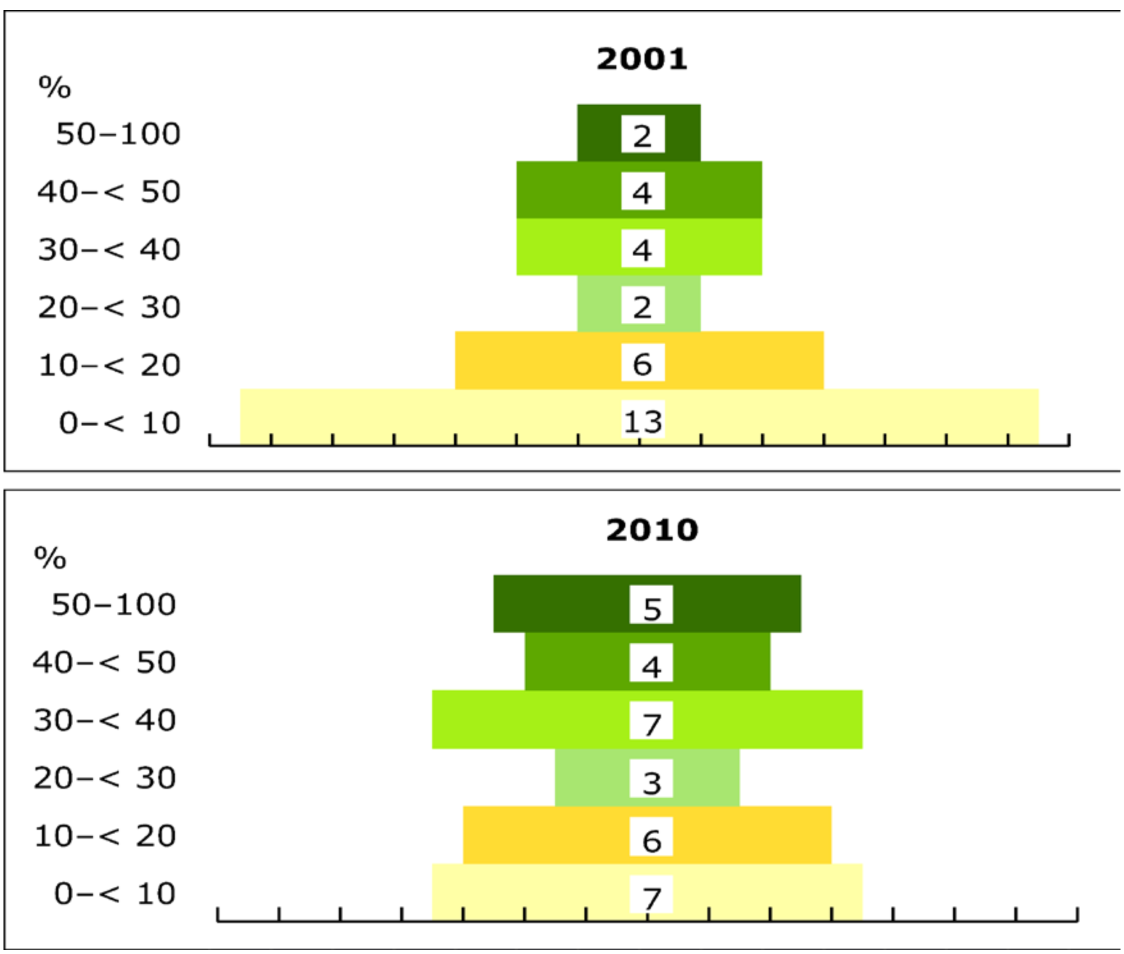


Figure 2.10: Progress in the number of European countries attaining higher recovery fractions of municipal solid waste materials (including organics) from 2001–2010 (European Environment Agency 2013a)

c.3 Policy lever: landfill ban or tax

Landfill bans are the most commonly cited policy solution to raise the re-use of household organic materials, and have already been widely implemented in the US (Figure 2.12). From a classical economic perspective, landfill bans are radical measures since they are equivalent to placing an infinitely high Pigouvian tax on landfilling. The strongest cases for landfill bans are in one of two camps. The first set of arguments is based on the idea that the environmental-economic externalities of landfilling organic material are poorly accounted for in landfill tipping fees (Finger Lakes Regional Sustainability Plan 2012). In other words, the general public is bearing additional burdens (e.g. pollution) that are not accounted for in the market price of tipping fees paid at landfills. The second argument is that the economy will benefit from enabling an industry that converts low-value wasted materials into higher value products such as biofuels and organic fertilizers (MRW 2013). This approach is considered sound on economic grounds given that raw material prices are rising due to increasing demand, and the reuse of wasted materials will offset that demand by supplying functionally equivalent products.

In both Europe and the US, there have been concerns regarding the effect of bans on the capacity of non-landfill waste treatment. In Denmark for example, the combustible MSW ban has led to increases in capacity beyond what can be handled by the existing infrastructure. Bans can remove flexibility from the system; landfills are more flexible to changes in throughput than treatments such as anaerobic digestion, SSF, composting, or incineration.

In Europe, the approach to landfill bans is different. Most often the entire stream of untreated municipal solid waste is banned from the landfill. The principal effects of wholesale bans on untreated MSW have been: 1) to reduce landfilling; 2) to increase the amount that is incinerated or sent to mechanical biological treatment such as anaerobic digestion, SSF, or composting; and 3) reduce the overall production of MSW (Bio Intelligence Service 2012).

A recent study for the European Commission does identify "a clear correlation between the total cost of landfilling and the percentage of municipal waste recycled and composted in the Member States" (Bio Intelligence Service 2012). While landfill bans place a large implicit cost on landfilling, it is equivocal whether categorical landfill bans (e.g. no organics) necessarily reduce the amount of household organic materials that are used in other pathways to make higher-value products. For example, Germany is a developed nation that excels at sustainable organic material management without a wholesale landfill ban on organic material. It has one of the highest recycling rates of municipal waste in Europe (ranked #2in overall MSW and #7 in organics). Important initiatives have been an educational focus on separate material collection, and support of both household source separation and private sector mechanical separation. German success in material recovery is aided by the high pre-tax cost of landfilling due to tipping fees in excess of 190 $/MT (over 140 €/MT), as Figure 2.11 shows. For comparison, tipping fees in the United States are average approximately 50 $/MT or 36 €/MT (Green Power Inc, 2011). The current tipping fee for landfills servicing the city of Rochester, NY is $60/ton (Waste Management 2013c).

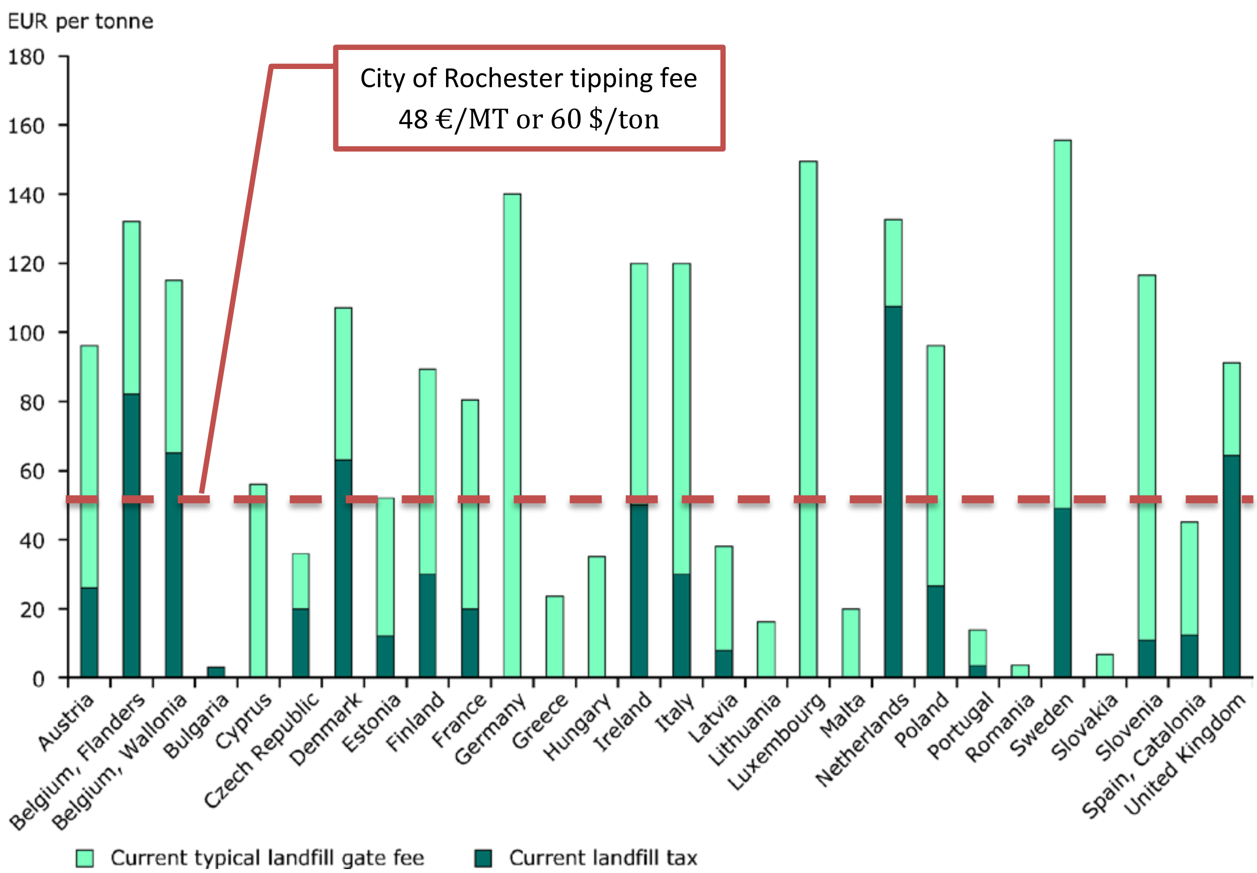


Figure 2.11: Typical charge (gate fee and landfill tax) for legal landfilling of non-hazardous municipal waste in EU Member States and region (European Environment Agency 2013a)

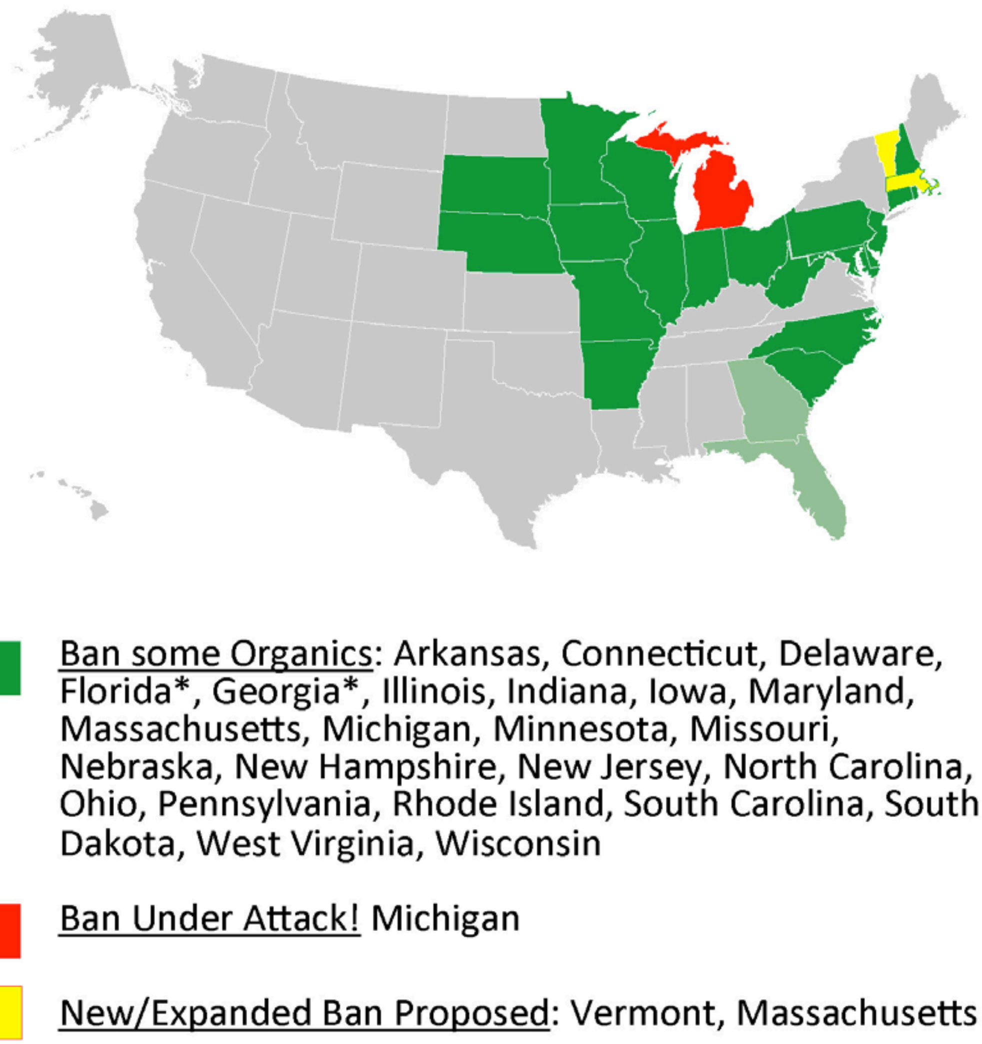


Figure 2.12: Map of state landfill bans on organic material (* indicates states where ban does not apply to landfills with gas capture) (Van Haaren et al. 2010)

Looking at Figure 2.12, we observe that landfill bans on organic material are not uncommon in the United States. In many of the states where they are in effect, only yard trimmings are prohibited, while food waste, compostable paper, and other organic material are allowed. In states such as Florida and Georgia, the ban does not apply to landfills with gas capture systems.

Currently in the United States, the State of Vermont is leading the way in organic material landfill banning policy. Vermont's Universal Recycling Law (i.e. Act 148) was passed in July 2012. Act 148 bans landfill disposal of plastic, aluminum and metal containers, tin foil, paper/cardboard, leaf/yard residuals and food scraps. The law makes Vermont the first state in the U.S. to require that all residential and commercial food scraps be "recycled" (i.e. diverted from landfill) by 2020. For now, the requirement is valid only if there is a permitted composting facility within 20 miles. In addition, that facility must have available capacity and be willing to take the organic material. By

2020, this stipulation will end in anticipation a developed statewide organics processing infrastructure. As Table 2.3 shows, compliance with the law is phased in over a series of six years, beginning with the largest generators of organic waste and ending with residential generators.

Table 2.3: Vermont food scraps landfill ban compliance schedule (Spencer 2014)

Date	Required compliance
7/1/2014	Generators over 104 tons/year must separate food scraps
7/1/2015	Generators over 52 tons/year must separate food scraps
7/1/2016	Generators over 26 tons/year must separate food scraps
7/1/2017	Generators over 18 tons/year must separate food scraps Food scraps must be collected at solid waste facilities Food scraps must be collected at curbside by haulers
7/1/2020	All food scraps are banned from landfill, including residential sources.

Act 148 was passed without funding for implementation. This implies that the State of Vermont expects the private sector to steadily pursue infrastructure development in response to increased organic material access. However, it is estimated that forty million dollars will be needed over the next nine years to support processing and collection of organics and traditional recyclables (e.g. paper, aluminum, glass) (Spencer 2014). Much of this investment will be made by the private sector, with additional investments and funding from solid waste districts. The state has indicated that it may provide support and seed money to help guide strategic investments furthering compliance with Vermont's Universal Recycling law (Spencer 2014).

c.4 Pay-as-you-throw weight-based fee for MSW collection

Pay-as-you-throw policy incentivizes waste reduction by charging residents based on the amount of material set out for collection, rather than charging a flat fee for MSW collection regardless of how much material is generated. This incentive structure causes many residents to reduce their material output in order to save money on their MSW collection bill. For household organic material recycling in particular, pay-as-you-throw (PAYT) policies are often used in tandem with MSW sorting policy (e.g. mandatory source separation of organic material) to further improve landfill diversion rates and reduce the MSW generated.

Vermont's Universal Recycling law (i.e. Act 148) made Vermont the first state to require pay-as-you-throw to incentivize the public to recycle in addition to a landfill ban (Spencer 2014). New York State has not implemented a landfill ban, but has demonstrated commitment to pay-as-you-throw. PAYT is widely implemented in New York State, and the NYSDEC has recommended that any sustainable organic material management strategy involve pay-as-you-throw MSW pricing policy (NYSDEC 2010). One can speculate that New York legislators would consider requiring pay-as-you-throw in the near future if the mandate proves effective in Vermont.

In Rochester, NY there is no PAYT policy in place. Instead, residents are charged a flat fee of $343 dollars per dwelling unit on their taxes. This offers no economic incentive to reduce MSW generation or encourage source separation of household organic material, as residents pay the same regardless of their behaviors. In line with the goals of the NYSDEC to increase source separation and reduce MSW generation, Chapter 4 in this research is a cost-benefit analysis (CBA) determining expected financial impacts to the City of Rochester and households of implementing a weight-based PAYT policy. PAYT is attractive to municipalities because it can be fully implemented in under a year (Skumatz and Freeman 2006) and show immediate results. It has been shown to reduce MSW generation up to 50-60% within one year of implementation in municipalities in Denmark, Austria, Italy, and Ireland (BioInformation service 2012). European countries using economic incentives such as PAYT for household materials that are not separately collected (i.e. organics, glass, metals, etc.) have performed better than countries where there is no direct incentive to reduce material generation (i.e. fees based on household size or flat fee programs). (European Environment Agency 2013a, 2013b, and 2013c). PAYT has also proven to be effective in US cities such as Austin, Texas; San Francisco, California; and Renton, WA. As of 2006, PAYT was employed in over 7,000 jurisdictions in the US (Skumatz and Freeman 2006).

c.5 Pay-as-you-throw pricing examples: Europe

Seventeen European nations employ pay-as-you-throw unit pricing policies – three of which (Austria, Finland, and Ireland) have the policy in every municipality. The policies fit the following categories (Bio Intelligence Services 2012):

- **Fixed annual fees per household based on cart size**: range up to $3344 in Stuttgart, Germany for a large 290 gallon bin (or $11.50/gal)
- **Fees for the purchase of mandatory refuse bags/tags for residual (i.e. non-separated) material:** range from $0.90 for a 4.5 gal bag (Argentona Municipality, Catalonia, Spain) to $7.62 for a 18.6 gal bag (for bags over and above standard volume collected, Stuttgart, Germany);
- **Fees per emptying of a bin:** range from $0.70 (in the context of a scheme combining volume and frequency elements, Ribeauvillé, France) to $5.84 (north Helsinki, Finland);

- **Fees per kg:** range from $0.25 (Slovakia) to $0.50 (Sweden)

c.6 Pay-as-you-throw pricing examples: United States

In Austin, Texas – considered one of the best-run cities in America by Sauter and Frolich (2014) – was a pioneer of MSW PAYT. Since 1990, PAYT has dramatically raised Austin's overall material landfill diversion rate from 9 to 35% (McHale 2010). Their weekly MSW output is down to 27 pounds per household each week – far outperforming the 84 pounds per household each week in Rochester, NY (assuming 5.15 pounds per capita each day with an average household size of 2.33) (NYSDEC 2008; United States Census 2010b). These results are surprising given that tipping fees in the Austin area are among the lowest in the United States – around $20 per short ton as opposed to $60 per short ton in the Rochester, NY area. Austin's fees (Table 2.4) range from $160-402 per year, compared to a $343 flat fee in Rochester, NY. Their unit rates range from $0.35/gal to $0.56/gal or $0.09/kg to $0.14/kg (which assumes the organic material has a density of 4.01 kg/gal (Forster-Carneiro et al. 2008)). Downsizing the cart is at no extra cost (unlike upsizing), which further encourages residents to source separate, generate less wasted material, and save money.

Table 2.4: Austin, Texas PAYT structure for MSW

Cart size (gal)	Volume-based rate ($/gal)	Mass-based rate ($/kg)	Monthly rate ($)	Yearly rate ($)
24	0.56	0.14	13.35	160.20
32	0.46	0.11	14.60	175.20
64	0.31	0.08	19.75	237.00
96	0.35	0.09	33.50	402.00

The Austin authorities began PAYT with a pilot program of 3,000 households, and once it was proven successful rolled it out city-wide. To help implement the program, Austin enlisted the help of volunteer block leaders to assist city staff in educating residents about the program. An additional pilot program has begun for household organic material. Starting in December 2012, Austin Resource Recovery began providing 14,000 households with weekly curbside collection of food scraps, compostable paper and yard trimmings. That pilot has since expanded to 25,000 residents.

d. Economic modeling of organic material management systems

The What'sBEST! Microsoft Excel economic model in Chapter 5 of this research determined the profit-maximizing management pathways for the three common household organic materials that account for a combined 30% of total MSW generation. The materials are excess food, yard trimmings, and compostable paper, and account for make 18%, 5%, and 7% of total MSW generation respectively (NYSDEC 2008). The Excel model may be used as a decision support tool for public and private decision makers in the city of Rochester, NY who wish to increase the profitability of the material management system by diversifying available organic material processing pathways. This particular work has not been attempted before, but there have been in-depth models leading up to it that have conducted economic optimizations specific areas of organic material management.

There have been recent efforts to model the economic feasibility of organic waste-to-energy systems that could potentially utilize source separated household organic material. In 2010, the Environmental Protection Agency released the *co-digestion economic analysis tool* (CoEAT). CoEAT is an MS Excel engineering economics model which aims at defining the; "initial economic feasibility of food waste co-digestion at wastewater treatment plants for the purpose of biogas production" (Environmental Protection Agency 2010).

The input parameters for CoEAT include: 1) population and feedstock sources; 2) type of existing solid waste and waste-water infrastructure; 3) material handling costs and tipping fees; 4) expected processing operation costs; 5) utility costs; and 6) discount rate. Outputs include: 1) assumed feedstock chemical makeup; 2) total handling costs; 3) required digester capacity and associated primary/ancillary capital costs; 4) net present value for the project.

The CoEAT model is strong in that it does not require the user to conduct an in-depth analysis of the feedstocks that are being used – rather it operates on assumptions about the make-up of material generally associated with different sources. However, CoEAT requires the user to have in-depth knowledge about operation and management costs (e.g. number of personnel; digester cleaning and repair). Considering only industry professionals would have this type of information, the model would not be useful for most municipalities and businesses that are considering diverting household organic material from landfill. Municipal and business decision-makers would require a comparison of all the available options so that they could make the profit-maximizing choice.

The modeling effort in this body of work seeks to determine the amount of locally available source separated organic material that should go to anaerobic digestion (among other pathways) based on potential economic output. However, the CoEAT model does not address the role of the anaerobic digestion pathway in a competitive environment where there are multiple other options which can also create revenue. As such, the focused lens of the CoEAT analysis does not assist decision makers that need to take into account the opportunity costs of taking material from one revenue-producing pathway (i.e. landfills with gas capture) and diverting it to another one (e.g. anaerobic digestion, SSF, or composting).

The EPA also developed a model called the Municipal Solid Waste Decision Support Tool (MSW-DST). It is designed to analyze the full cost and life cycle environmental impacts for alternative MSW strategies. The model is targeted to broad audiences in the private, public, and non-profit sectors, but assumes knowledge of full cost accounting and life cycle assessment. It allows for decision makers to model household collection of organic material, but it currently does not include AD or SSF processes. The EPA consultants who developed the MSW-DST have developed off-line models for those pathways, but have not come to a generic standard model for each (RTI international 2014). RTI plans to build a model including AD and SSF in the future (RTI international 2014). This modeling effort provides useful data and preliminary economic results to help its development.

Chapter 3: Household organic material management survey of Rochester, NY residents in the Southeast section of the city

a. Goals

A survey tool was developed to shed light on the expected social sustainability of a household organic material source separation and collection program under pay-as-you-throw MSW pricing policy. In order for the system to be socially sustainable, residents need to be motivated to participate in two core activities: organic material separation and collection. Since resident motivations are multi-faceted, the survey involved financial, practical and values-oriented questions. Areas of inquiry included: willingness-to-pay for source separated organic material collection, current management behaviors, experiences with current organic material collection program participation (i.e. the Community Compositing subscription), awareness and perceptions of organic waste-to-energy pathways, engagement in urban agriculture and social capital.

b. Methodology

b.1 Selecting Southeast Rochester, NY residents as survey population

Although the survey was open to all residents within the City of Rochester, NY (zip codes 14602-14964)a specific effort was made to gather data on potential organic collection program participants in the Southeast Quadrant (zip codes 14620, 14610, 14607, 14618). This quadrant of the city makes for an interesting case study as residents in the Southeast have the highest median income in the city of Rochester. Therefore, they have a relatively small economic incentive to participate in household organic material collection under a weight-based MSW fee policy, where money is saved by removing organic material from the billable MSW stream. Economically speaking, the Southeast presents a "worst-case scenario" for participation based on the financial incentive of MSW collection fee savings. When considered as a conservative estimate of resident participation in organic material separation and collection, the findings relating to economic incentives to participate are generalizable to the city of Rochester as a whole. On the other hand, high income and homogenous demographics (i.e. highly educated, Caucasian) in the Southeast limit the applicability of values-oriented motivations to participate in a household organic material collection program. Residents with different educational and racial/ethnic backgrounds may have widely differing values. However, since the Southeast is a viable place for a pilot program to test municipal weight-based PAYT fee policy, these values-oriented motivations are still worth exploring.

b.2 Selecting survey population sub-groups

The survey included two sub-groups: residents who are already participating in an organic collection program (i.e. subscribing to Community Composting) and residents who are not. City of Rochester, NY residents that are subscribed to Community Composting are of particular interest for this study. This is because they are already engaged in a source separated household organic material collection system provided by Community Composting. The pilot business has had success; Community Composting has over 400 subscribers and currently serves an area covering ten city of Rochester, NY zip codes. As of 5/5/2014, nearly 27 MT of household organic material has been diverted from landfill via Community Composting.

Community Composting, LLC is a small, independent business that operates in the city of Rochester, NY. The founders of the business, inspired by successful composting in other US cities, found that many Rochester, NY residents expressed a desire to turn household organic material into useful compost. However, many also explained that they lacked the facilities, time or tools to compost. Community Composting provides two main services 1) fresh compost delivery and 2) comprehensive household organic material collection. The core business activity of Community Composting is hauling household organic material to a local compost producer from subscribing households, and returning compost co-product from SSF to the doorstep. The compost co-product is composed of 50% large particle size residual solids from the fermentation process, and 50% water. Each week, subscribers to Community Composting are provided clean buckets for curbside collection of their organic material and then their filled buckets are hauled away. Once each month, the compost is delivered to subscribers during weekly organic material collection. The compost made from local household organic material (e.g. excess food, yard trimmings and compostable paper) is a microbially active soil amendment, high in natural plant fertilizers. Each month, subscribers have the option of donating their compost share to a local community garden or receiving a potted herb.

Surveys were distributed digitally through environmental group networks based in the Southeast quadrant. They were also sent via e-mail to Community Composting subscribers – which are most numerous in the Southeast quadrant. Because existing organic material management assets in the Southeast are strong (e.g. environmental activism groups, active neighborhood/business associations, a farmer’s market, present urban agriculture) it would be a prime location for a larger curbside organic material collection pilot program.

b.2 Survey population statistical significance

The survey period was from 8/21/13 to 10/3/13 and had a total of 36 multiple choice, Likert scale, and extended response questions. The survey is an attachment in Appendix A. Survey results are displayed in the aggregate (all City of Rochester, NY residents) and in subgroups (Community Composting participants and not participating in Community Composting). The sample size was n = 92. The margin of error for this sample size is 10.21% assuming a 95% confidence level. This was calculated assuming a simple random sample of 78,517 individuals (United States Census 2010b) in the Southeast quadrant of the city of Rochester (i.e. zip codes 14620, 14610, 14607, 14618). The survey respondents are homogenous (77% are from the Southeast quadrant of the city and 89% are Caucasian). It is important to note that the Southeast quadrant does not match the demographics of the city of Rochester, NY population. This data reflects a local context in the city, so values-oriented findings (as opposed to findings related to financial incentives) are not generalizable to a large, diverse population like the city of Rochester, NY.

Out of ninety-two total respondents, forty three were Community Composting subscribers and forty nine were not. A resident survey conducted in Wollongong, Australia suggests that income, household consumption, education and length of residence were not consistent in differentiating between households actively engaged in normatively constituted 'pro-environmental' behaviors (Gibson et al. 2011). This suggests that even a relatively homogenous survey population can provide relevant results about household behavior.

c. Results and discussion

c.1 General questions

These questions asked what households do with organic material such as excess food, yard trimmings, and soiled kitchen paper (i.e. greasy pizza boxes, used paper towels, etc.) and inquired about participation in material management programs.

Question #1 explored how likely it would be for a household to produce less garbage if it saved money to do so. Figure 3.1 shows the results.

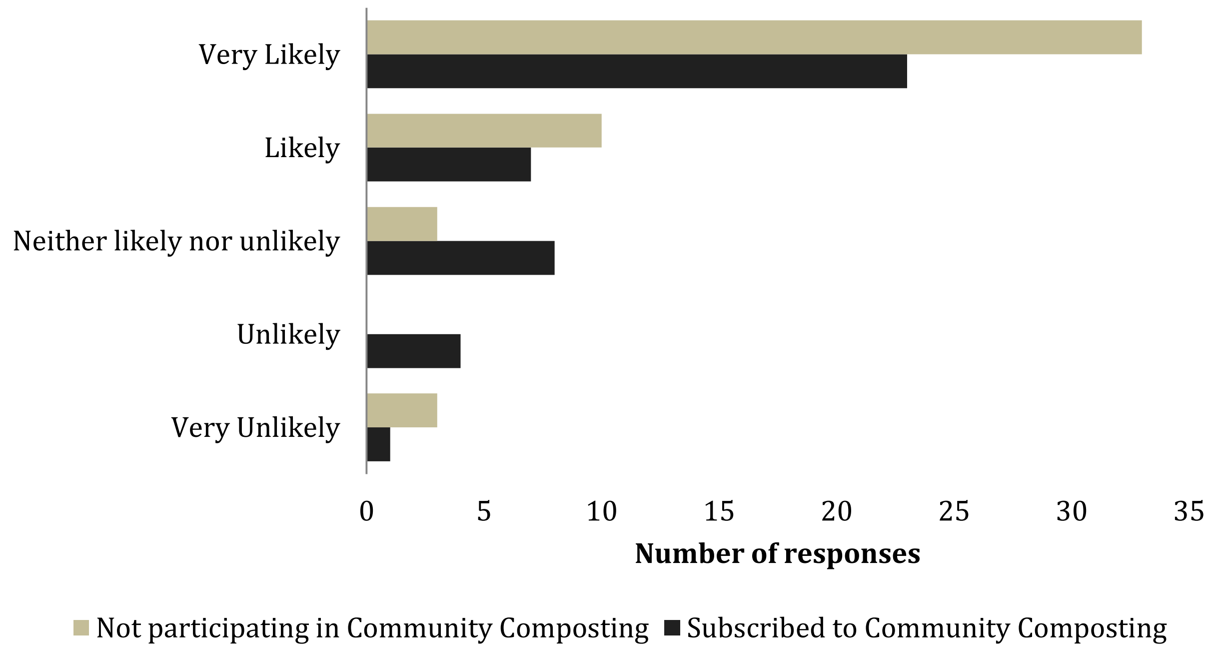


Figure 3.1: City residents' likelihood to produce less garbage if it saved money to do so, grouped by Community Composting subscription status

Interpretation: 61% of respondents believe they are very likely to produce less garbage (i.e. achieve source reduction) assuming there is an economic incentive to do so. A small minority (8%) of respondents are either unlikely or very unlikely to change their habits toward greater source reduction if money could be saved. Interestingly, 67% of those who are *not* currently subscribed to Community Composting say they are "very likely" or "likely" to reduce garbage if they could save money by doing so. 53% of those who *are* subscribed replied they are "very likely" or "likely" to reduce garbage if they could save money by doing so. These findings suggest that economic incentives to reduce garbage – i.e. pay-as-you-throw MSW pricing – will induce a majority of residents in Southeast Rochester, NY to reduce garbage output. The one stipulation to achieve source reduction is that the economic incentive must be positive, that is to say that household budgets must increase under PAYT MSW pricing.

Question #2 asked how likely it would be for households to participate in an organic material collection program if it saved money to do so. Figure 3.2 shows the results.

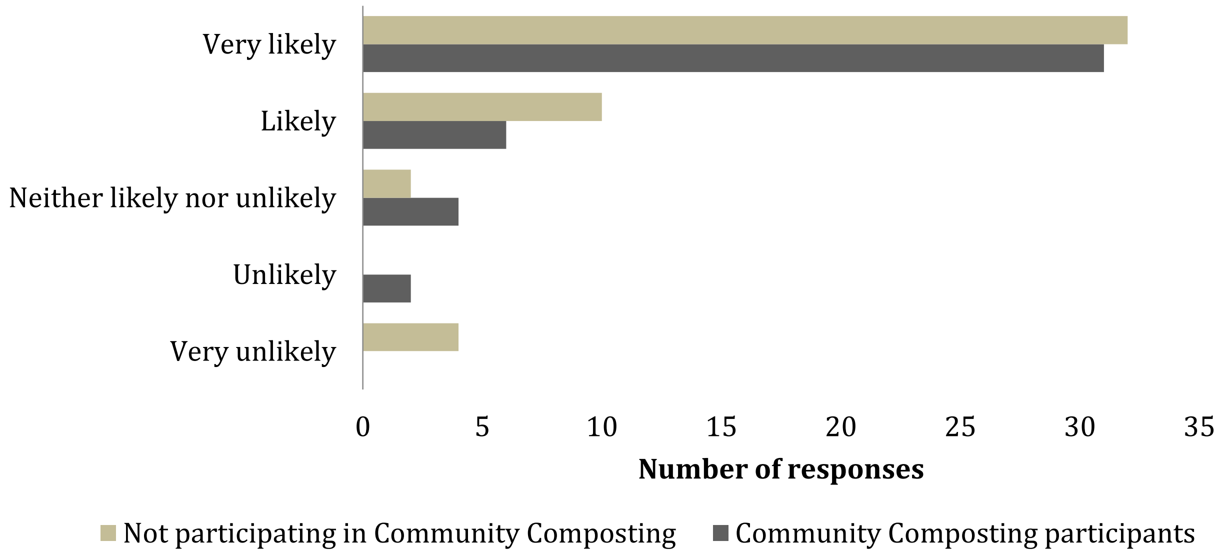


Figure 3.2: City residents' likelihood to participate in an organic material collection program if it saved money to do so, by Community Composting subscription status

Interpretation: 85% of respondents replied that they would be "very likely" (67%) or "likely" (18%) to participate in an organic material collection program if it saved money to do so. There was little difference in the replies of Community Composting subscribers and non-subscribers.

Question #3 inquired about participation in home composting. Respondents were asked whether or not they currently compost their household organic material at their home. Figure 3.3 shows the aggregate results, and Figure 3.4 shows the results broken down by Community Composting subscription status.

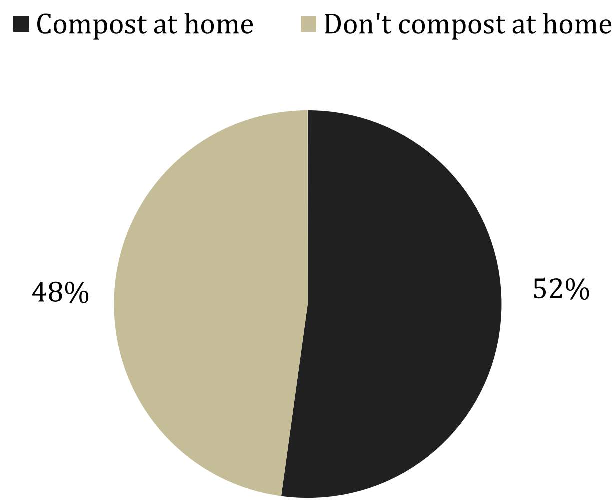


Figure 3.3: City residents' participation in home composting

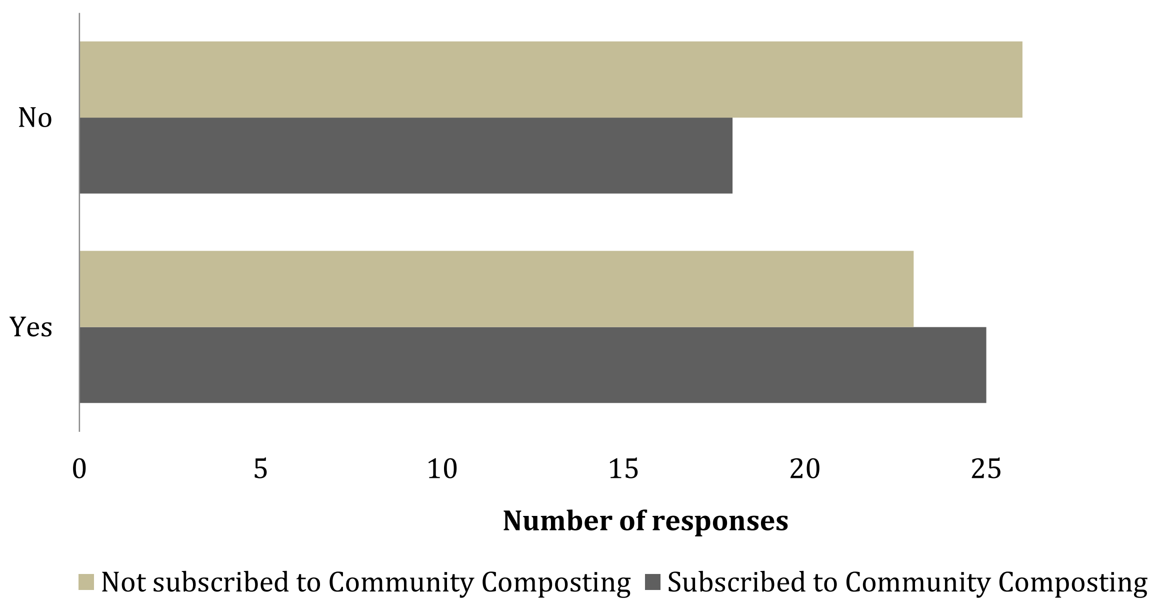


Figure 3.4: City residents' participation in home composting, grouped by Community Composting subscription status

Interpretation: In the aggregate, over half (52%) of residents participate in home composting. However, the actual number of participants in home composting may be over-represented. Some of the subscribers to Community Composting may have interpreted their participation in the waste-to-ethanol program to be home composting even though it is not. Since subscribers indirectly compost their food through Community Composting which delivers finished compost co-product from the waste-to-ethanol process, this possible interpretation would give a slightly higher amount of Community Composting respondents who compost at home.

Question #4 explored why people do not compost at home. Among people who are not subscribed to Community Composting, there were a range of responses. The main themes from the responses are summarized below by utilizing actual answers from responding city residents.

- "I live in an apartment and don't have enough space"
- "No garden for the compost"
- "No time"
- "Rats in the neighborhood"
- "Don't compost food due to the smell. Do compost yard waste"
- "Never tried it, but it seems difficult"

Among people who <u>are subscribed to Community Composting</u>, there were some similarities:

- "Time and space are limited"
- "Frowned upon to compost at my apartment"
- "Concerned about the smell"
- "Don't know how to do it"

… as well as some differences:

- "Subscribed to Community Composting"
- "We use our garbage disposal when possible"

c.2 Economics of household organic material management

These questions asked about the financial aspects of managing household organic material as well as the interest in purchasing the products of alternative management pathways.

Question #5 asked residents about their willingness to pay each week for curbside collection of source separated organic material. Options were given for residents to indicate that they would require payment to participate as opposed to paying for the collection service. Figure 3.5 depicts the results.

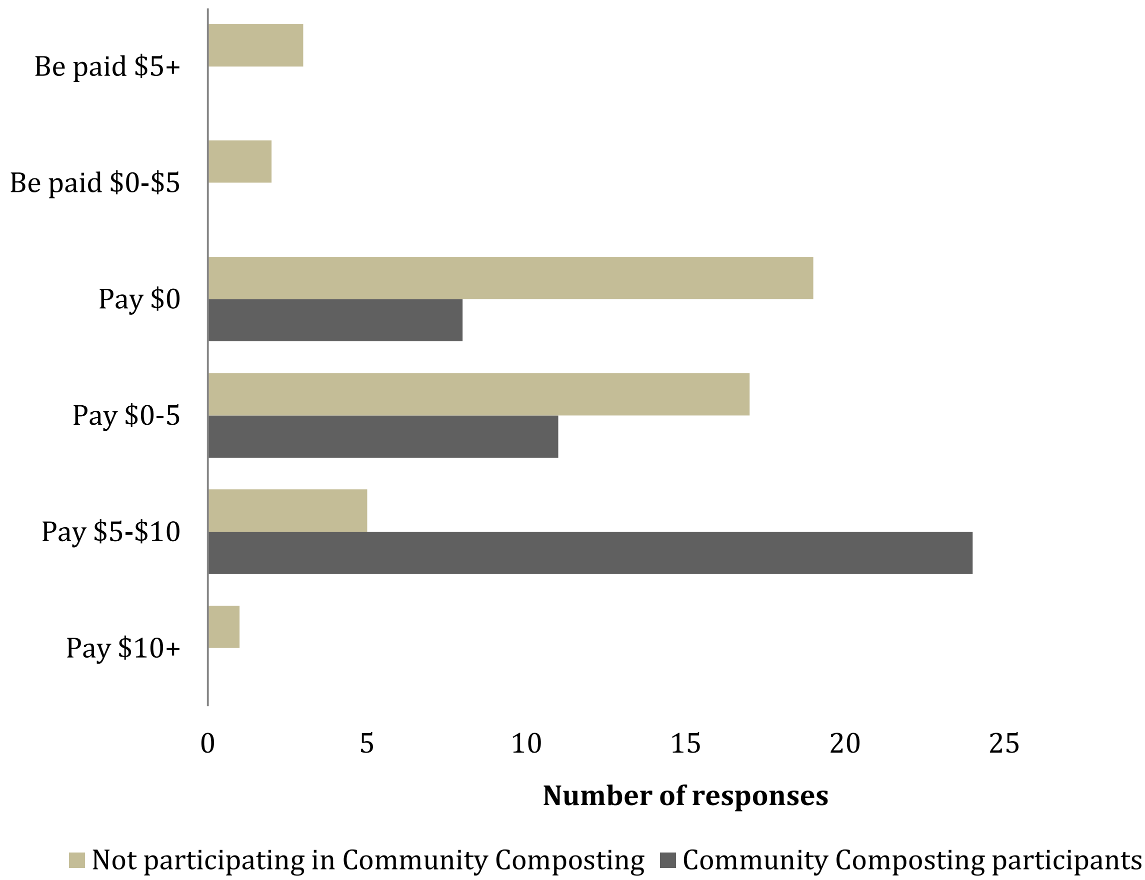


Figure 3.5: Rochester, NY residents' willingness to pay (or be paid) for curbside collection of household organic material, grouped by Community Composting subscription status

Interpretation: A price ceiling for curbside collection of household organic material can be defined as the highest market price possible before service demand sharply declines. In Figure 3.5, one can see sharp drop-offs in willingness-to-pay at certain price ceilings for each group. Among subscribers, the high end of the price ceiling is $10 per week. For non-subscribers the high end of the price ceiling is $5. The fact that subscribers are willing to pay more makes sense, as this group is already paying up to $7 per week to have their household organic material picked up in return for monthly compost.

Question #6 asked residents if they would accept separate pickup of household organic material and garbage once every two weeks. Figure 3.6 shows the results.

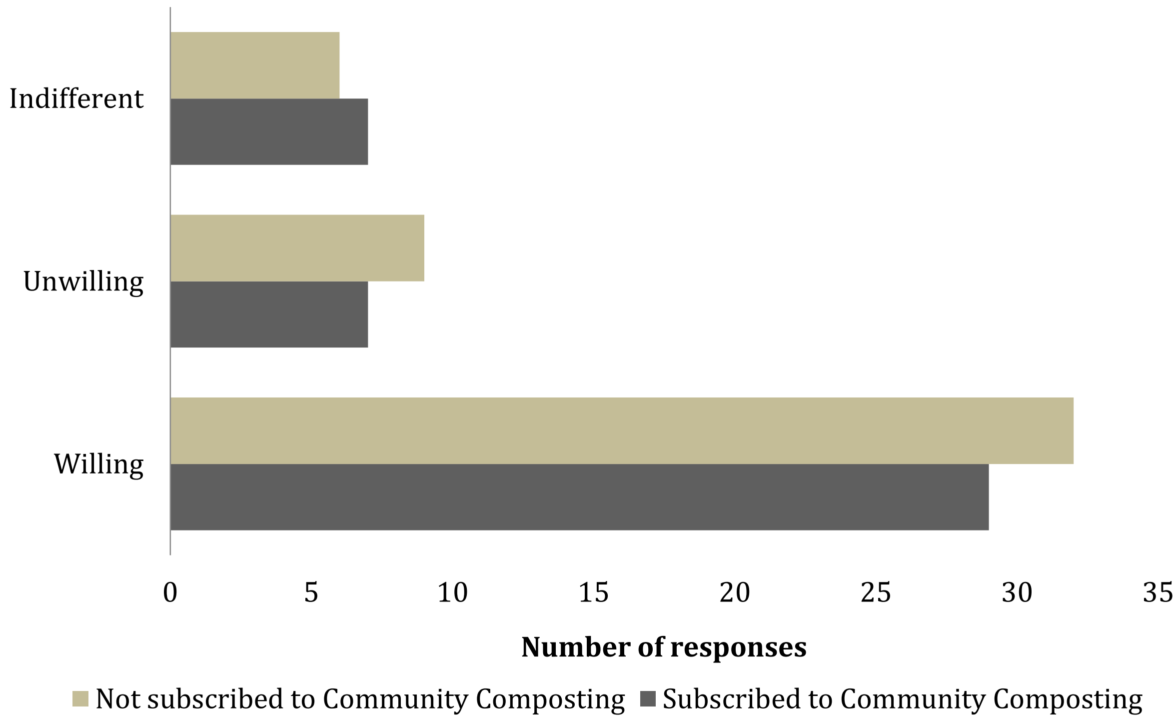


Figure 3.6: Rochester, NY resident's willingness to accept collection of source separated organic material and garbage once every two weeks, grouped by Community Composting subscription status

Interpretation: Most residents (66%) are willing to accept collection of source separated organic material and garbage. There is little variation in responses between Community Composting subscribers and non-subscribers. Since Rochester, NY currently collects MSW on a weekly basis, allowing residents to opt for one collection every two weeks is an opportunity to reduce the amount of municipally operated truck transport needed to manage organic material and garbage. This is assuming that conventional garbage trucks are retrofited to transport household organic material in a manner similar to how other re-usable materials (e.g. plastics, metals) are collected. A benefit of household source separation of organic material is reduction in odors caused by decomposing material, thus allowing MSW to sit at the curb for longer without being collected. The fraction of MSW that is source separated household organic material could be collected by commercial enterprises looking to profit from making products out of the material.

Question #7 asked about residents' willingness-to-pay to have a community drop-off point for source separated organic material. Figure 3.7 shows the results.

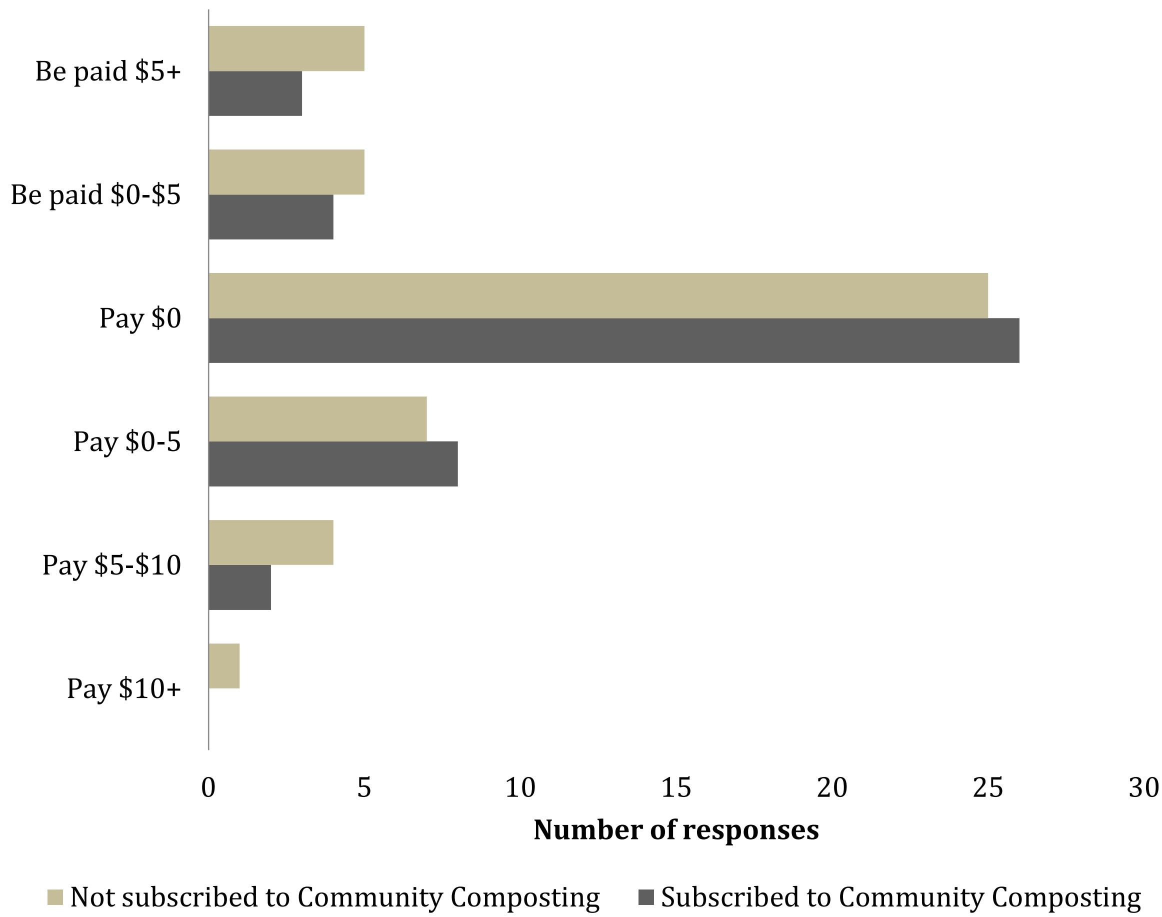


Figure 3.7: Rochester, NY resident's willingness to pay (or be paid) for a community drop-off point for source separated organic material, grouped by Community Composting subscription status

Interpretation: Residents are largely indifferent to the presence of a community drop-off point for their source separated organics, since the vast majority (74%) would not be willing to pay a positive sum for a local drop-off point. About a quarter (24%) of respondents are willing to pay a positive amount. The results are consistent between the Community Composting subscribers and non-subscribers.

Question #8 focused on the maximum distance residents would likely travel to a community drop-off point for household organic material. Figure 3.8 shows the results.

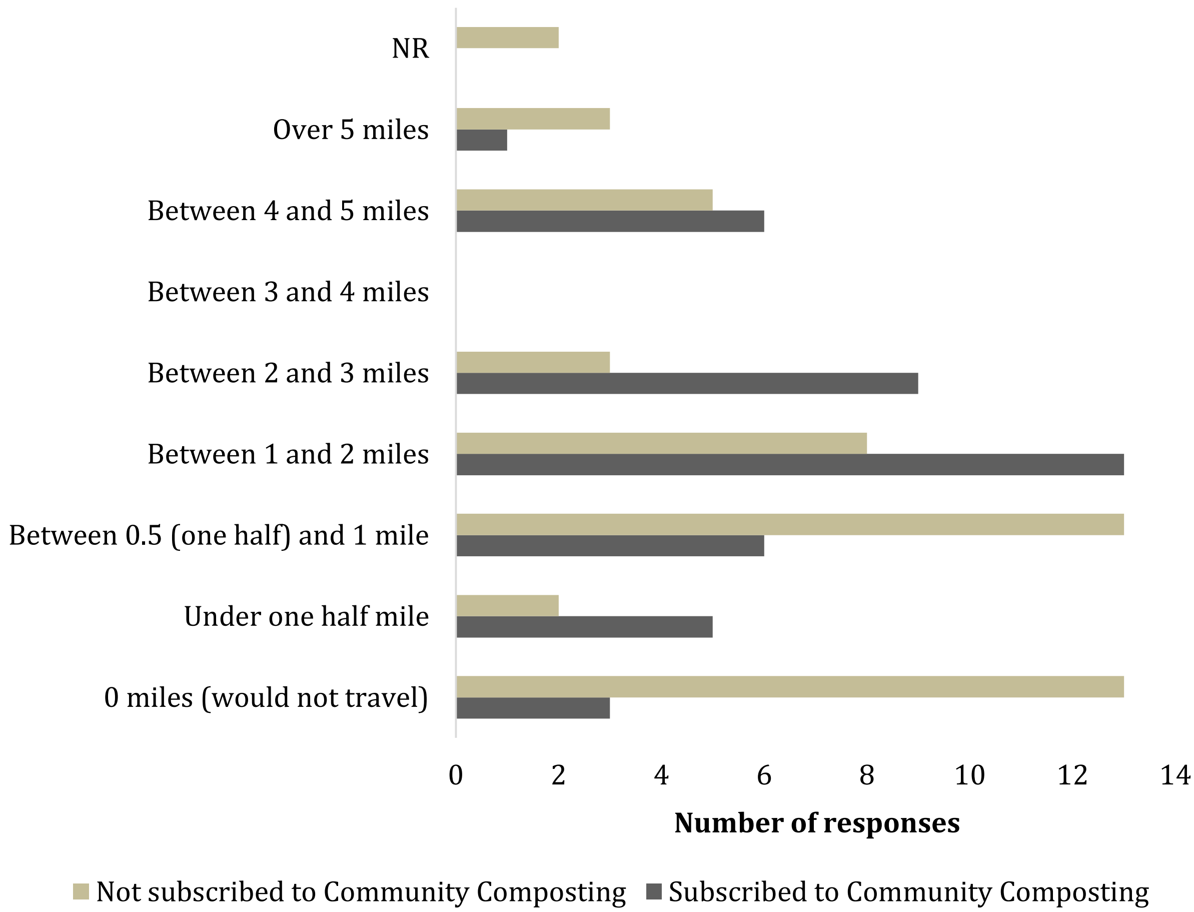


Figure 3.8: The maximum distance residents would travel to an organic material drop-off point from their households, grouped by Community Composting subscription status

Interpretation: Many more residents would travel to a community drop-off point than those who would not. This claim is stronger in the Community Composting subscriber group than in the non-subscriber group. There is significant variation in acceptable travel distance between Community Composting subscribers and non-subscribers. Those who are already paying for organic collection through Community Composting would be willing to travel farther than non-subscribers. The mode for subscribers was "between 1 and 2 miles" and for non-subscribers the mode was split between "half mile and a mile "and "would not travel".

Question #9 asked residents about their interest in purchasing renewable energy made from household organic material from Rochester, NY. Figure 3.9 shows the results.

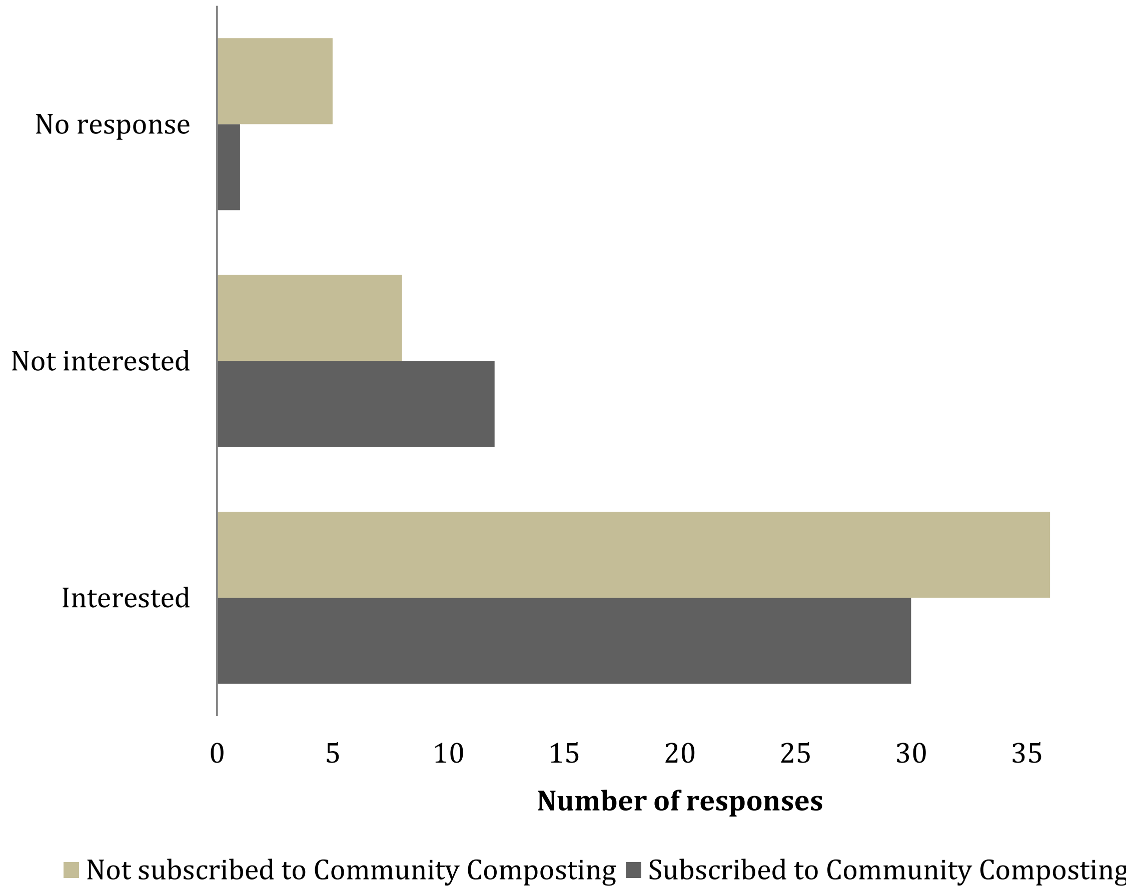


Figure 3.9: Resident interest in purchasing renewable energy made from household organic material from Rochester, NY, grouped by Community Composting subscription status

Interpretation: 72% of residents are interested in purchasing renewable energy made from their household organic material, compared to 22% not interested. This suggests that energy created from local organic material is demanded by residents who are open to switching from the incumbent.

Question #10 asked residents about their interest in purchasing compost made from their household organic material. Figure 3.10 shows the results.

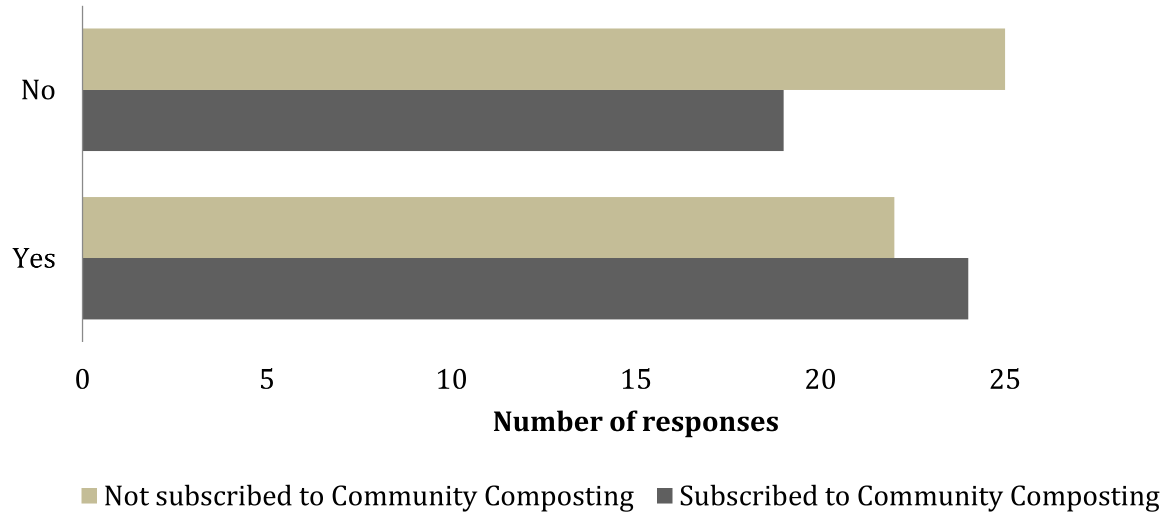


Figure 3.10: Rochester, NY resident interest in purchasing compost made from household organic material from Rochester, NY, grouped by Community Composting subscription status

Interpretation: In the aggregate, 50% of residents are interested in purchasing compost using household organic material from Rochester, NY. Community Composting subscribers are slightly more likely than non-subscribers to purchase compost from local household organic material – which is not surprising considering they already are purchasing the product through their subscription.

c.3 Social implications of expanded household organic material management

These questions asked about the social impacts (i.e. community engagement, local food growing) that may accompany a sustainable organic material management system.

Question #11 asked about the extent to which residents' are aware of the social impacts of landfilling their household organic material. Figure 3.11 shows the results.

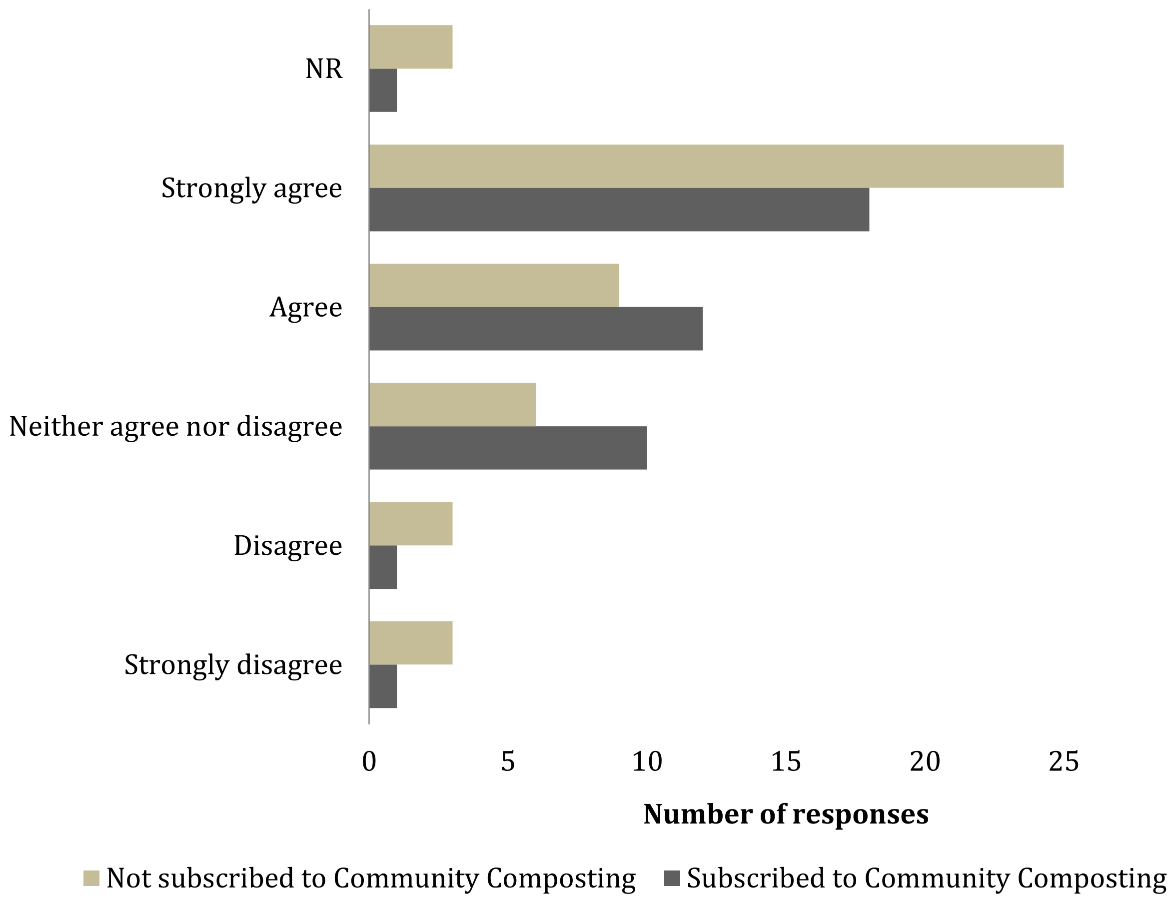


Figure 3.11: Residents' agreement with the statement "I am aware of the social impacts of throwing away my household organic material to the landfill", grouped by Community Composting subscription status

Interpretation: 47% of residents strongly agreed with the statement; "I am aware of the social impacts of throwing away my household organic material to the landfill". A strong majority (70%) either agreed or strongly agreed, while only 8% either disagreed or strongly disagreed. This suggests that most residents think they are cognizant of how landfilling organic material impacts their society.

Question #12 asked about the extent to which residents desire more engagement with their neighbors. Figure 3.12 shows the results.

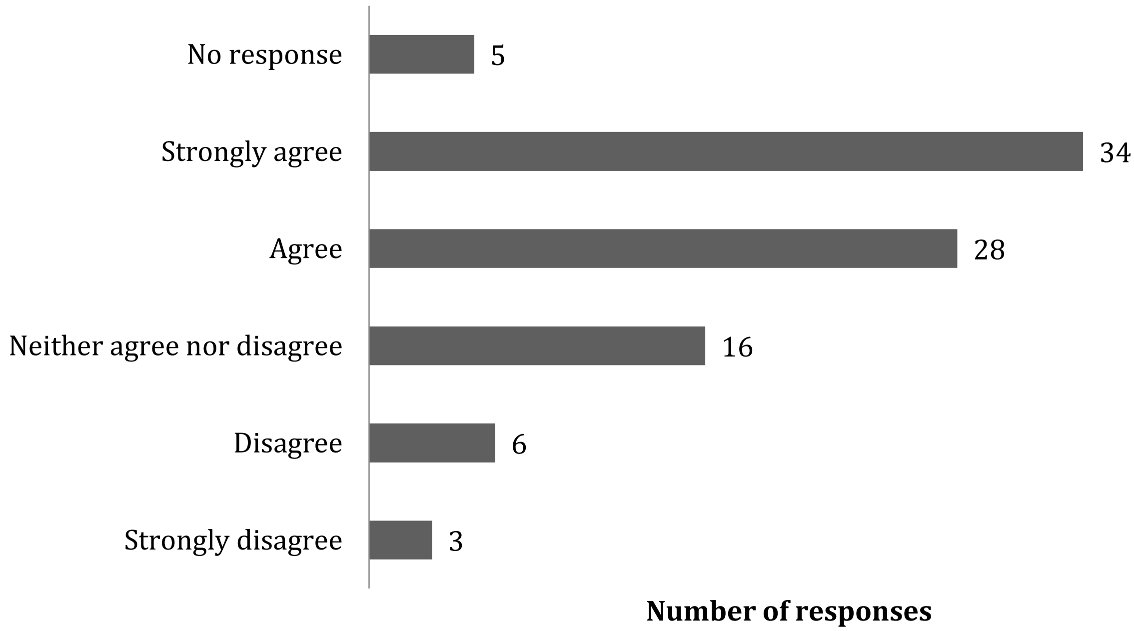


Figure 3.12: City residents' (in aggregate) agreement with the statement "I have a desire for more local community engagement with my neighbors"

Interpretation: Most residents (67%) reported that they have a desire for more engagement with their neighbors. The largest group of respondents (37%) chose that they "strongly agree" that they desire more engagement. As such, there is a potential opportunity to get residents to invest time in projects at the neighborhood level (i.e. community garden or community-supported organic collection). The Community Composting service offers steep discounts for getting neighbors to sign on together for a group subscription that shares a pickup point, thereby keeping collection costs down (see Appendix D). A demand for more community engagement could be facilitated through an organics collection incentive such as this which will cause neighbors to interact on a weekly basis.

Question #13 asked about the number of neighbors that city residents interact with each week. The results are below in Figure 3.13.

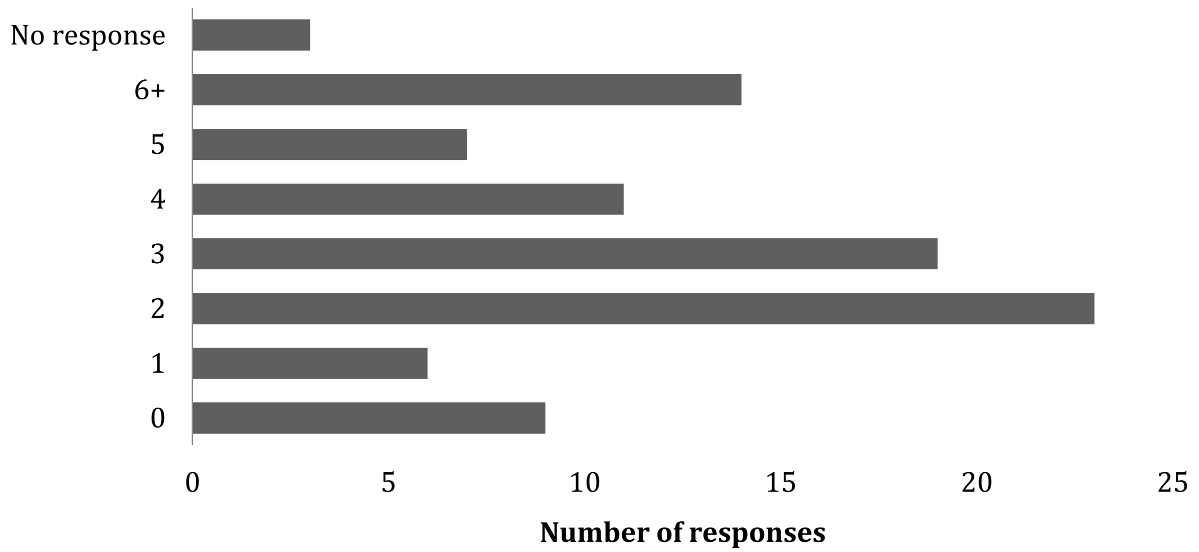


Figure 3.13: Number of neighbors that Rochester, NY residents reported interacting with per week

Interpretation: There are more people who interact with multiple neighbors each week (80%) than those who only interact with one or none (16%). At the extremes, 15% of respondents mentioned that they interact with 6 or more people neighbors per week, as opposed to 10% interacting with none. The wide presence of existing relationships suggests a potential for cooperation among neighbors in household organic material separation and collection to reduce costs. Results are consistent among Community Composting subscribers and non-subscribers.

Question #14 asked residents about their interest in growing their own food. The results are shown in Figure 3.14.

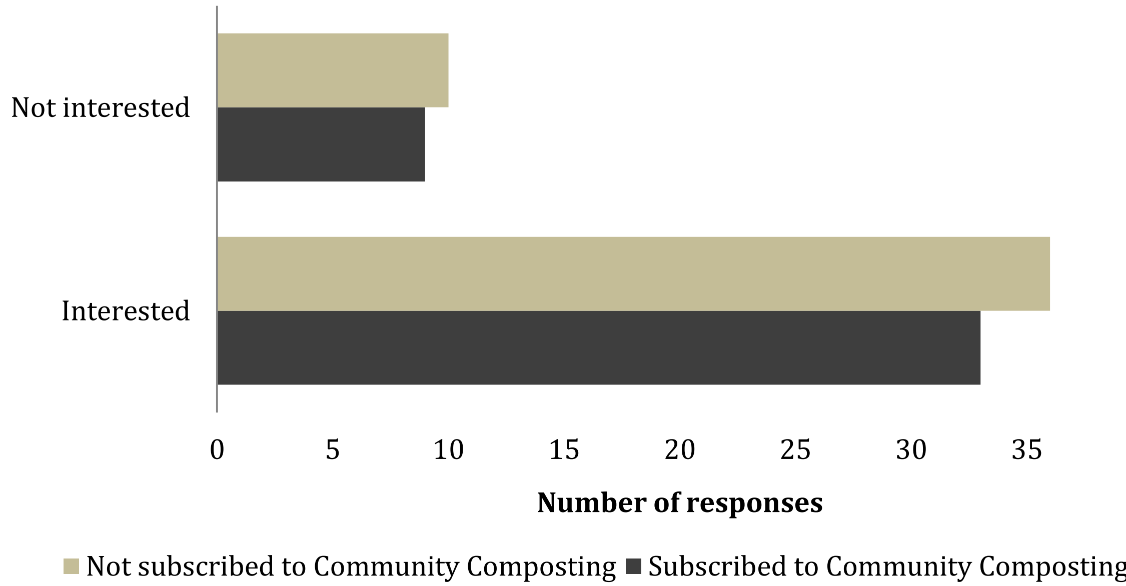


Figure 3.14: Interest in growing food among Rochester, NY residents, grouped by Community Composting subscription status

Interpretation: In the aggregate, 75% of residents were interested in growing their own food, compared to 21% not interested (and 4% not responding). The interest was nearly the same between both subgroups. This result suggests demand for more urban agriculture businesses, or home and community gardens for local food production. These operations could choose to utilize electricity, fuel, and compost from treated household organic material in the city of Rochester, NY.

Question #15 asked residents to indicate what types of edible and inedible crops they had grown in the past year. Figure 3.15 shows the results.

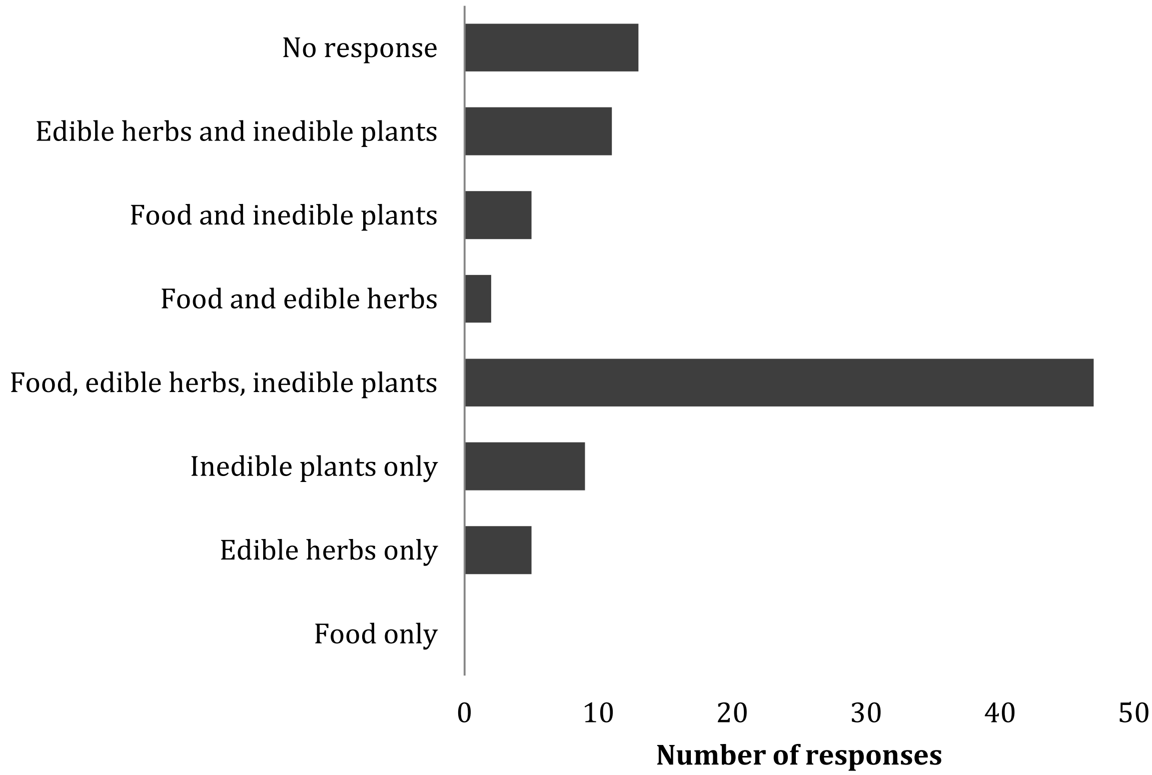


Figure 3.15: Crop types (i.e. food, inedible plants, and edible herbs) in Rochester, NY resident urban agriculture over the past year

Interpretation: A strong majority (76%) of residents grow edible herbs or food crops. The most common approach is to grow food, edible herbs and inedible plants together (51%). Only a small amount of residents (14%) did not respond, which means that 76% is the minimum percentage of residents that grow edible plants. Comparing Figure 3.15 to Figure 3.14 from the previous question, the percent of residents growing dedicated food crops is smaller than the percent interested in growing food (58% compared to 75%). This suggests latent demand for local urban agriculture.

Question #16 asked whether residents grow their crops at home, in a community space, or both. Figure 3.16 shows the results.

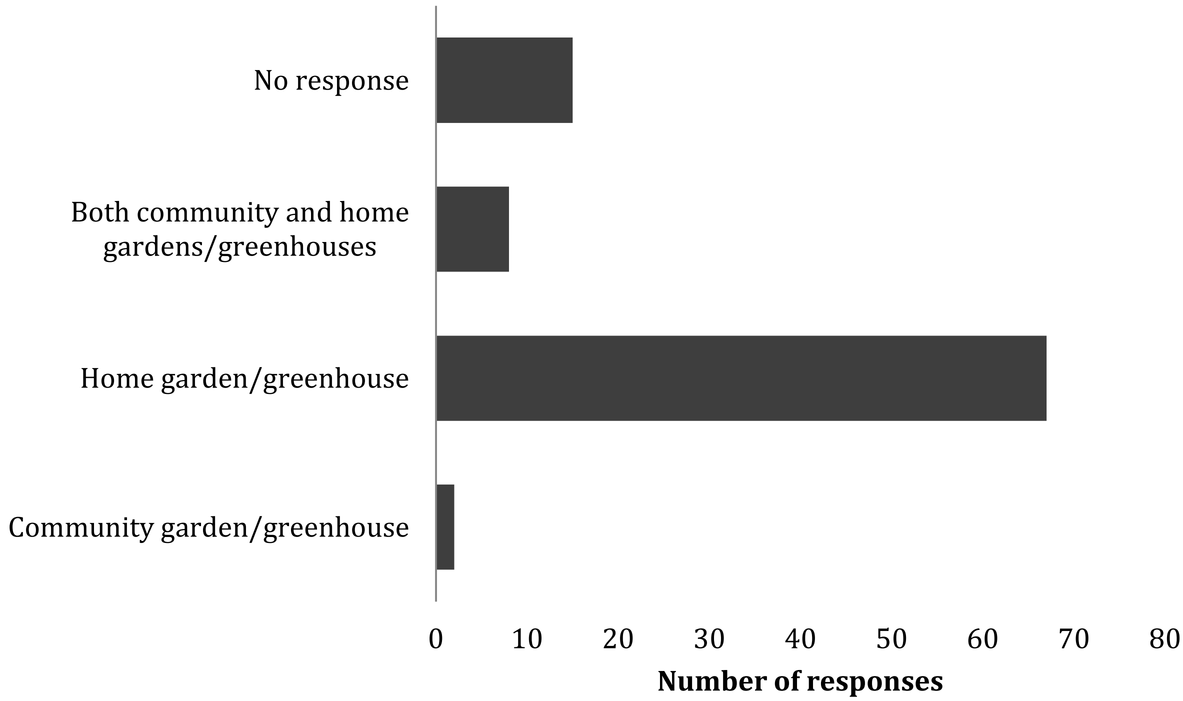


Figure 3.16: Residents' gardening activity by location (i.e. home or community space)

Interpretation: The vast majority (73%) of resident gardening takes place at private residences. There are a relatively large percentage of home gardeners compared to community gardeners (73% to 11%). This may suggest that community gardening is underdeveloped, considering the high overall percentage of urban farmers (76%). The prominent behavior of private gardening is surprising, considering that most residents (67%) desire or strongly desire more interaction with their neighbors. Perhaps there is demand for more community agriculture but there are barriers preventing it. There is a reported shortage of quality soil for resident agriculture in the city of Rochester, NY .In addition, city code requires raised beds and safe, external soil for all city-permitted urban farming on city lots (Saxe 2013).

c.4 Environmental aspects of household organic material management

These questions explored how alternative household organic material pathways may impact the environment. Residents were asked about their awareness and support of opportunities for local organic waste-to-energy systems using household organic material.

Question #17 explored residents' awareness of the environmental impacts of landfilling household organic material. Figure 3.17 shows the results.

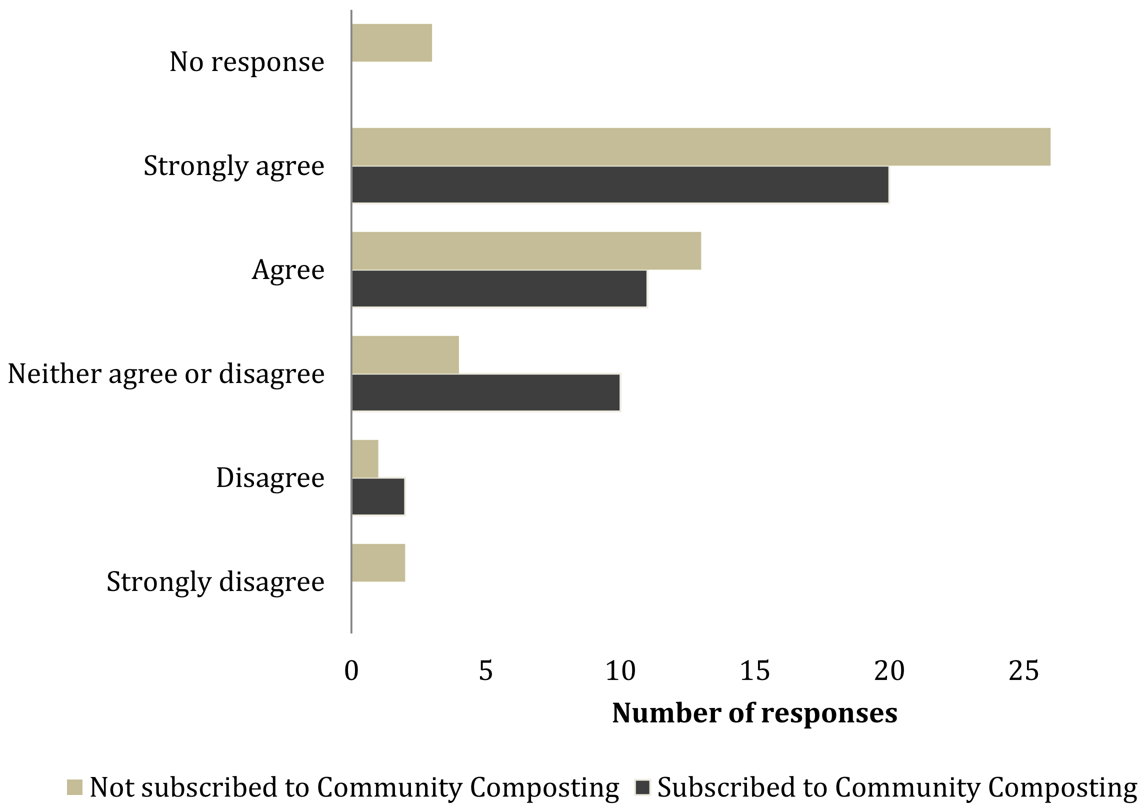


Figure 3.17: City residents' agreement with the statement; "I am conscious of the environmental impacts of throwing away my household organic material to the landfill", grouped by Community Composting subscription status

Interpretation: In the aggregate, 76% of city residents agree or strongly agree that they are conscious of the environmental impacts of landfilling household organic material. This result reflects a highly environmentally-conscious survey population.

Question #18 explored city residents' desire to improve the environment. Figure 3.18 shows the results.

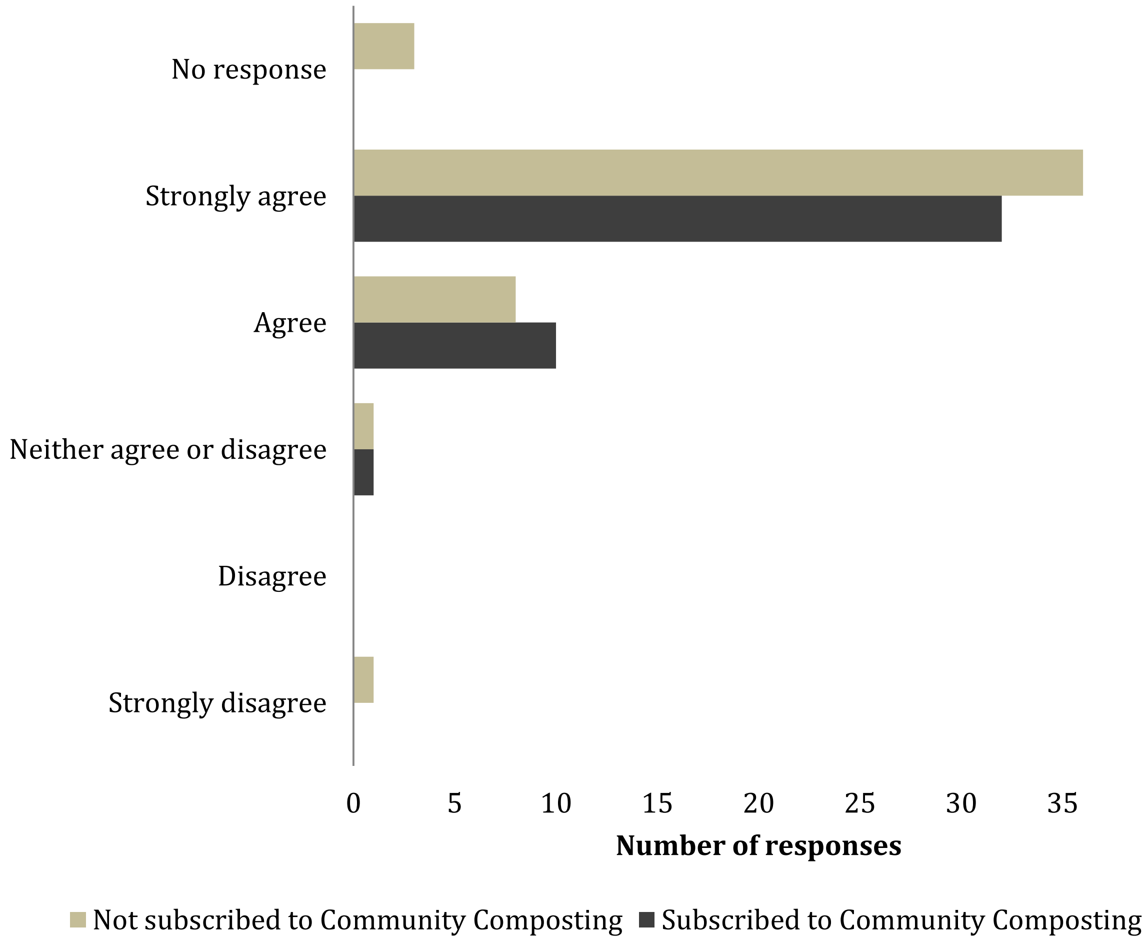


Figure 3.18: City residents' agreement with the statement; "I have a desire to improve the environment", grouped by Community Composting subscription status

Interpretation: Nearly all of the respondents (93% of 92 surveyed) either agree or strongly agree that they have a desire to improve the environment. The Community Composting subscription status did not have a significant effect on the responses to this question. This suggests that there is strong resident interest in supporting initiatives that produce an environmental benefit.

Question #19 asked about residents' preference for the end-of-life management pathway of their household organic material. Figure 3.19 shows the results.

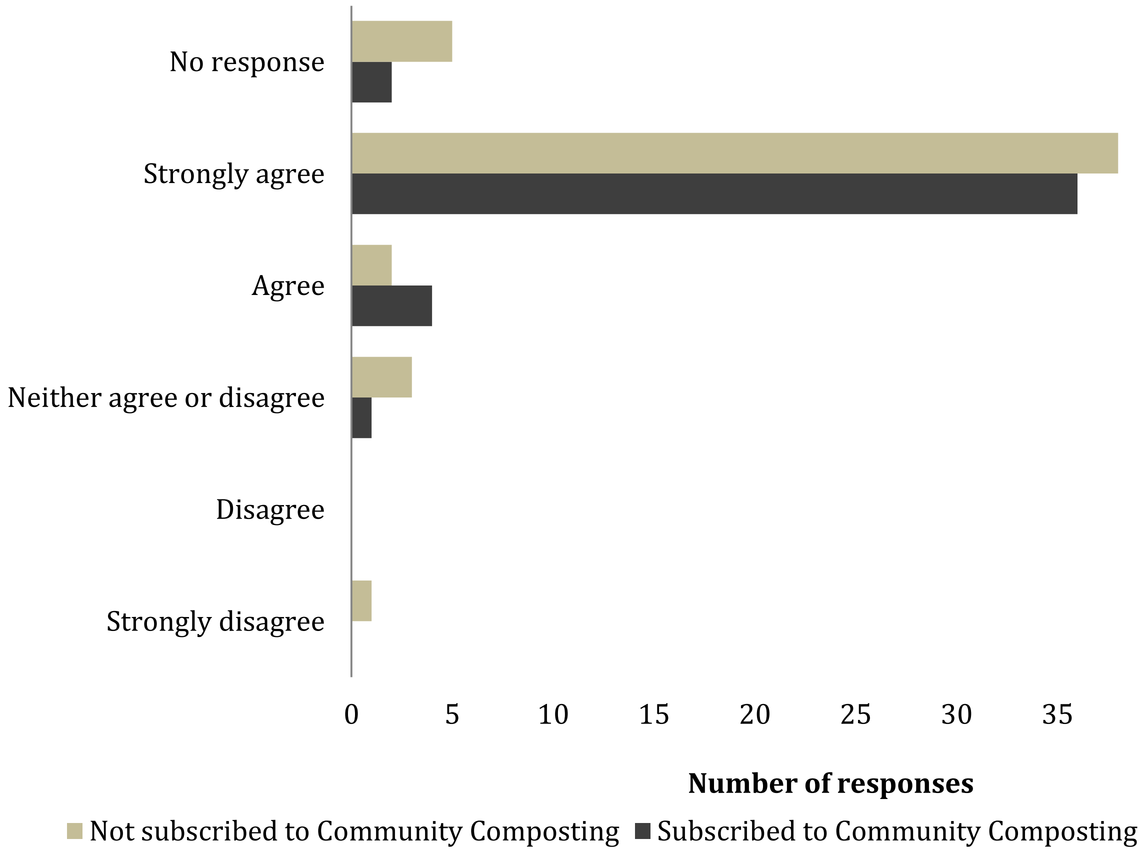
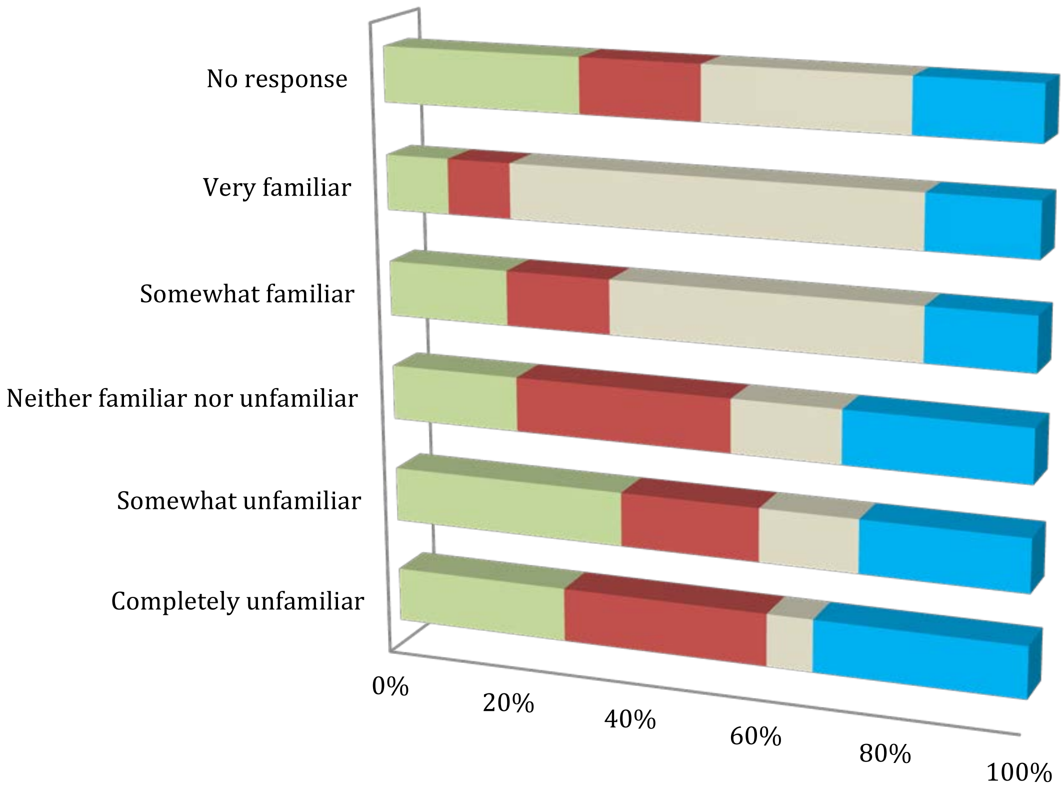


Figure 3.19: City residents' agreement with the statement; "I prefer that my household organic material be made into energy or compost instead of going to a landfill", grouped by Community Composting subscription status

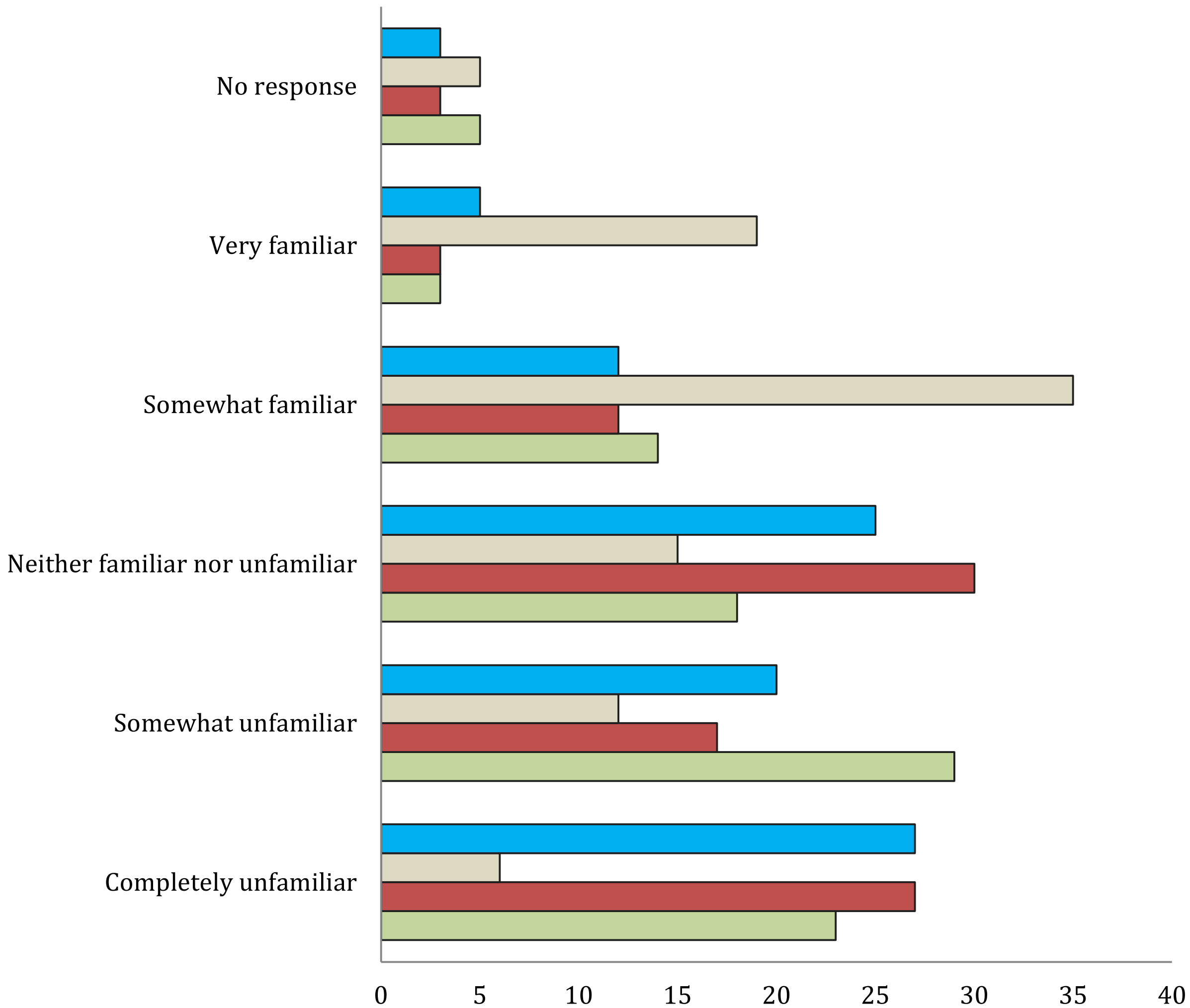
Interpretation: A strong majority (87% of 92 surveyed) of residents agree or strongly agree that they prefer their household organic material to be made into energy or compost instead of going to a landfill. This suggests that there would be majority support for initiatives that operationalize the alternative management pathways to landfill. Community Composting subscription status did not have a significant effect on the responses to this question.

Questions #20-23 focused on residents' level of familiarity with the management pathways for organic material. They were asked to rate their level of familiarity with the use of each pathway on a Likert scale from "completely unfamiliar" (1) to "very familiar" (5). Figure 3.20.1 compares the four technologies based on the percentage of responses at each familiarity level on the Likert sale. Figure 3.20.2 compares the total number of responses side-by-side.



	Completely unfamiliar	Somewhat unfamiliar	Neither familiar nor unfamiliar	Somewhat familiar	Very familiar	No response
Anaerobic Digestion	25.0%	31.5%	19.6%	15.2%	3.3%	5.4%
Ethanol fermentation	29.3%	18.5%	32.6%	13.0%	3.3%	3.3%
Composting	6.5%	13.0%	16.3%	38.0%	20.7%	5.4%
Landfill with gas capture	29.3%	21.7%	27.2%	13.0%	5.4%	3.3%

Figure 3.20.1: Percentage breakdown of respondents reporting their degree of familiarity with four organic material management technologies



	Completely unfamiliar	Somewhat unfamiliar	Neither familiar nor unfamiliar	Somewhat familiar	Very familiar	No response
Landfill with gas capture	27	20	25	12	5	3
Composting	6	12	15	35	19	5
Ethanol fermentation	27	17	30	12	3	3
Anaerobic Digestion	23	29	18	14	3	5

Figure 3.20.2: Residents' familiarity with four organic material management technologies (i.e. landfill with gas capture, composting, SSF, and anaerobic digestion)

Interpretation (summary): relative to other technologies, composting is the most familiar, followed by ethanol fermentation, anaerobic digestion, and landfills with gas capture in that order. Specific analysis for each of the four organic material processing pathways is bulleted below.

- **Composting**: most commonly viewed as "somewhat familiar" (38%). Yet, composting is best understood by Rochester, NY residents among the four organic material management technologies. As Figure 3.20.1 shows, composting was the least common technology to be viewed as "somewhat unfamiliar" or "completely unfamiliar" (13% and 7% respectively). Conversely, composting was the most commonly reported technology among "very familiar" (21%) and "somewhat familiar" (38%) categories. This means that 25% of respondents viewed composting as "somewhat unfamiliar" or "completely unfamiliar" compared to 59% who viewed composting as "very familiar" or "somewhat familiar".

  Figure 3.20.1 demonstrates that the percentage of respondents reporting anaerobic digestion, landfill with gas capture, and SSF as "very familiar" and "somewhat familiar" were not statistically different. The three technologies had between 13-15% reporting they were "very familiar", and only 3-5% for "somewhat familiar". Compared to composting, respondents were five times less likely to be "very familiar" with any of the other three.

- **Ethanol fermentation:** most commonly viewed as "neither familiar nor unfamiliar" (33%), and it is more commonly viewed this way than the other technologies. Ethanol SSF is second most commonly viewed as "completely unfamiliar" (29%), and third most commonly as "somewhat unfamiliar" (19%).

- **Anaerobic digestion:** most commonly viewed as "somewhat unfamiliar" (32%). It has the highest proportion of responses in this category than any other technology. 25% of respondents viewed anaerobic digestion as "completely unfamiliar". 20% are neither familiar nor unfamiliar with anaerobic digestion.

- **Landfills with gas capture**: most commonly viewed as "completely unfamiliar" (29%) followed closely by neither familiar nor unfamiliar (27%). Landfills are tied with SSF for the highest percentage (29%) of respondents that view it as "completely unfamiliar".

Question #20 explored residents' familiarity with anaerobic digestion to make methane from organic material. Figure 3.21 shows the results.

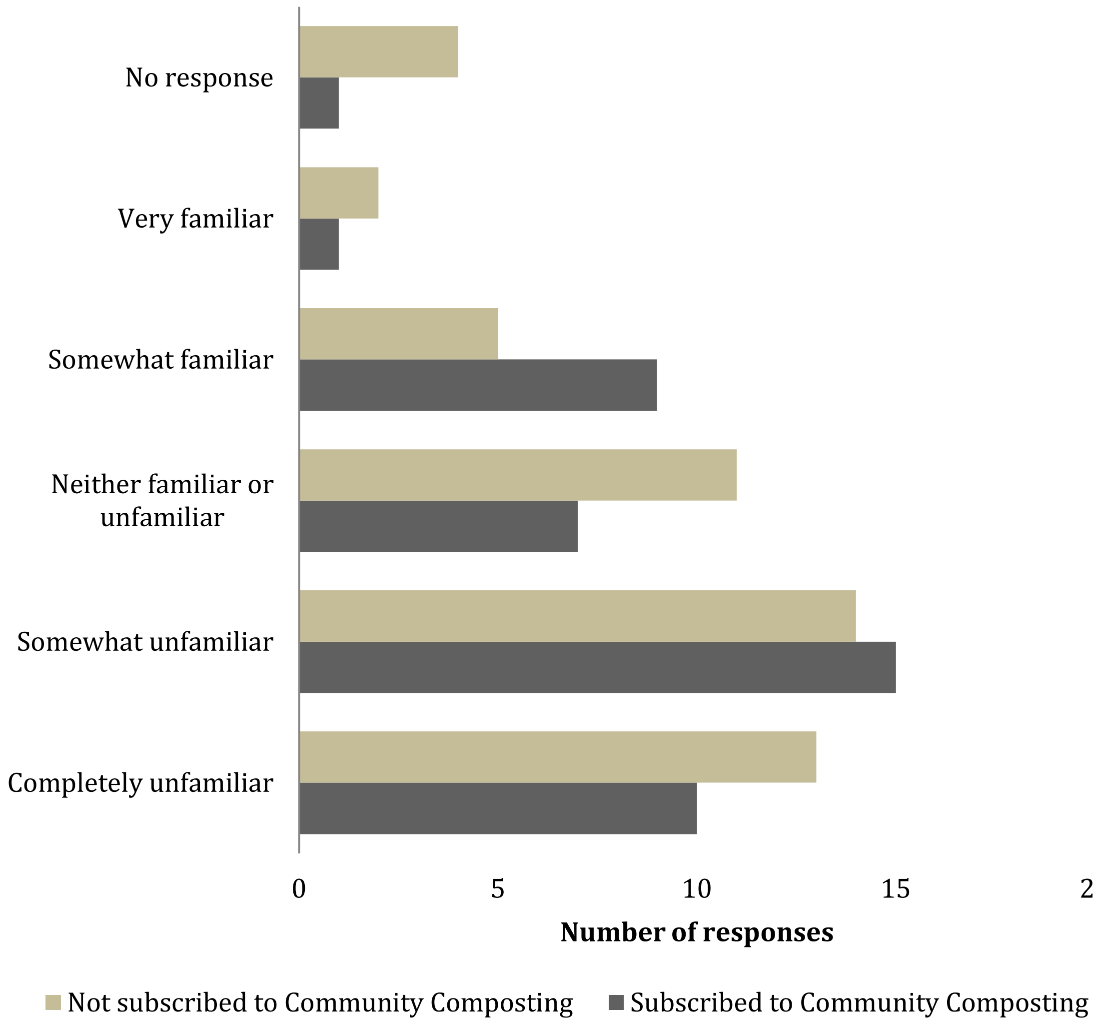


Figure 3.21: Residents' familiarity with using anaerobic digestion to produce methane from organic material, grouped by Community Composting subscription status

Interpretation: Only 18% of the aggregate population of residents is familiar or very familiar with using anaerobic digestion to produce methane from organic material. Non-subscribers to Community Composting had higher levels of "no response" and "completely unfamiliar". This may indicate that those participating in organic source separation for organic waste-to-energy (i.e. Community Composting subscribers) are more likely to have at least some familiarity with this household organic material management alternative.

Question #21 asked residents about their familiarity with using composting to produce soil amendments from organic material. Figure 3.22 shows the results.

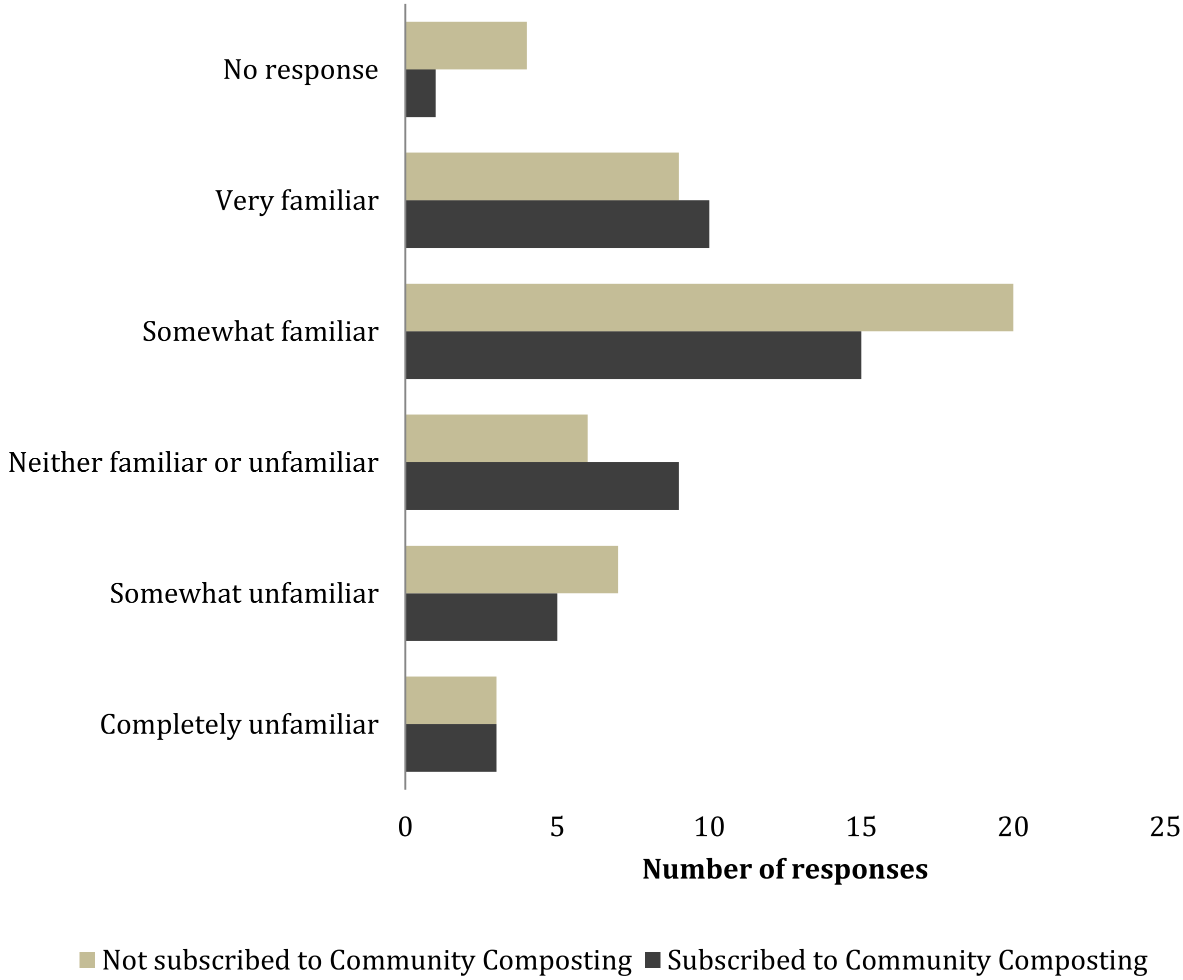


Figure 3.22: Residents' familiarity with using composting to produce soil amendments from organic material, grouped by Community Composting subscription status

Interpretation: A 59% majority of the aggregate population of residents reported that they are "very familiar" or "somewhat familiar" with composting organic material. Only 20% reported being "somewhat unfamiliar" or "completely unfamiliar" with using the pathway. There were no significant differences in responses between residents who are subscribed to Community Composting and those who are not.

Question #22 asked residents about their familiarity with using fermentation to make ethanol fuel from organic material. Figure 3.23 shows the results.

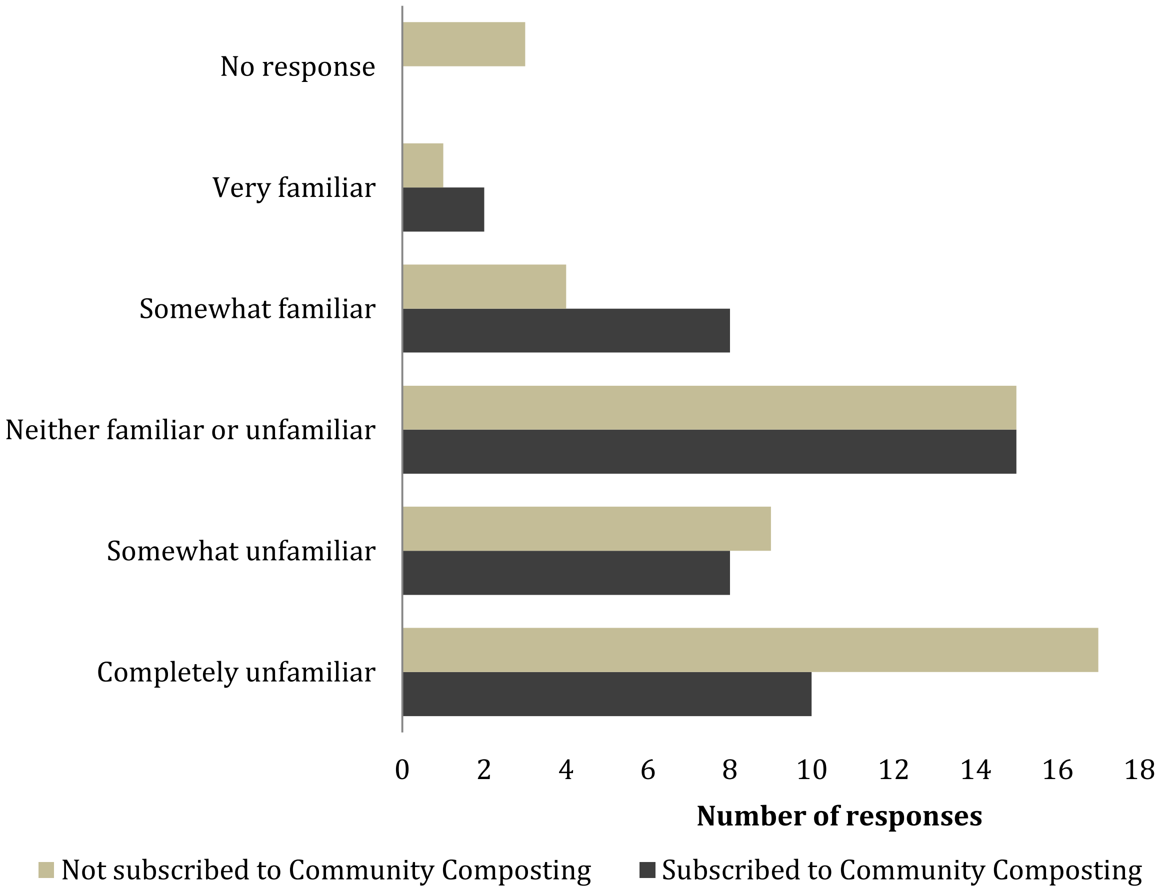


Figure 3.23: Residents' familiarity with using fermentation to make ethanol fuel from organic material, grouped by Community Composting subscription status

Interpretation: A 16% minority of the aggregate population of residents reported being "somewhat familiar" or "very familiar" with fermenting organic material. In comparison, we see that 29% of the aggregate population reported that they were "completely unfamiliar" with the process – higher than those that reported some familiarity.

It is interesting to note that the Community Composting subscribers are currently participating in a waste-to-ethanol program which produces ethanol from their household organic material. In this group, the same number of respondents reported they are "completely unfamiliar" as those who reported being "very familiar" and "somewhat familiar" combined. This finding is counter-intuitive, as one would assume that involvement in waste-to-ethanol would introduce participants to the process. Perhaps waste-to-ethanol participants in Community Composting are only concerned about the product being delivered to them (compost) and not how it is produced.

However, Community Composting subscribers overall had fewer reports of "completely unfamiliar", "somewhat unfamiliar" and "no response" than non-subscribers that are not participating in waste-to-ethanol. This indicates that participation in the waste-to-ethanol system has an effect on familiarity with the waste-to-ethanol pathway itself.

Question #23 asked residents about their familiarity with using landfill gas capture to make methane biogas from organic material. Figure 3.24 shows the results.

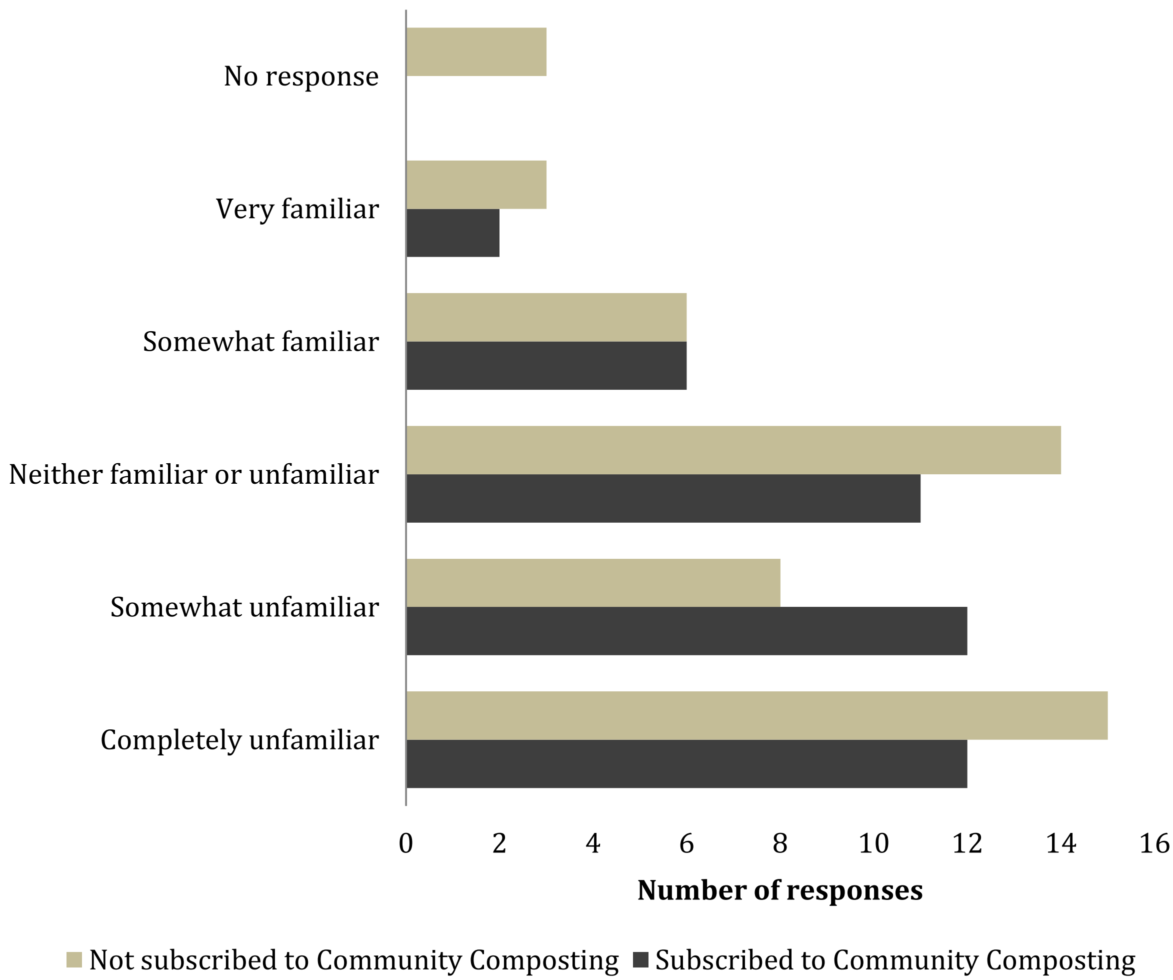


Figure 3.24: Residents' familiarity with using landfill gas capture to make methane biogas from organic material, grouped by Community Composting subscription status

Interpretation: A 51% majority of the aggregate population of residents reported being "somewhat unfamiliar" or "completely unfamiliar" with using landfill gas capture to make methane biogas from organic material. In contrast only 18% reported being "very familiar" or "somewhat familiar" with the process. There were no significant differences in the responses of residents with different Community Composting subscription status.

Question #24 explored if residents perceived excess food, yard trimmings, and soiled kitchen paper as waste. Residents were asked about the extent to which they agree that such organic material is not waste. Figure 3.25 shows the results.

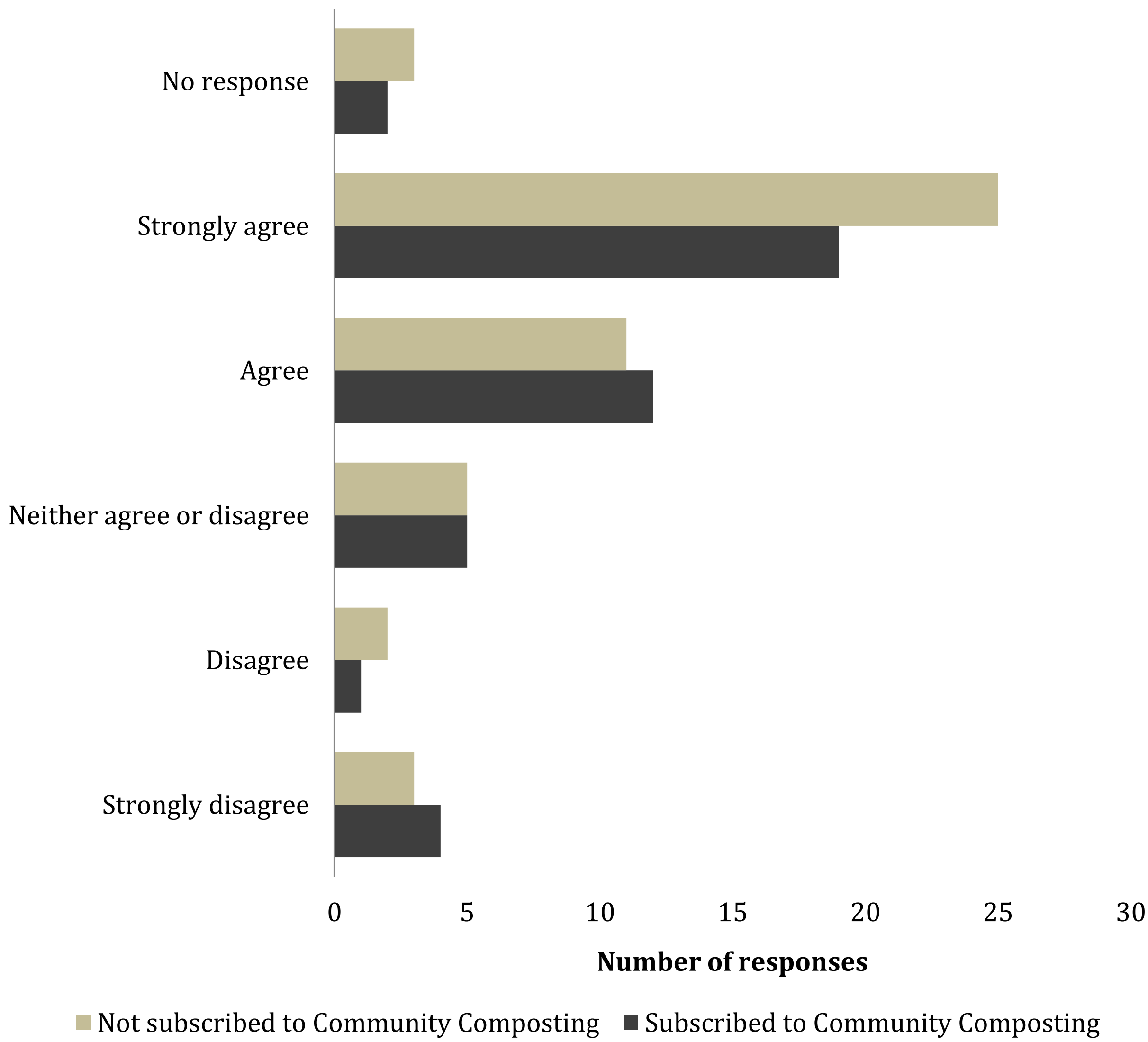


Figure 3.25: Residents' agreement with the statement; "Organic material such as food, yard trimmings, and soiled paper is not waste", grouped by Community Composting subscription status

Interpretation: A strong 73% majority of the aggregate population of residents "agree" or "strongly agree" that food, yard trimmings, and soiled paper is *not waste*. Surprisingly, those who are not subscribed to Community Composting are more likely to "strongly agree" that the organic material is not a waste. These are encouraging statistics for the implementation of expanded organic waste-to-energy in Rochester, NY, as there is sound awareness that something valuable can be done with household organic material – even among those who are not currently engaged in an alternative management pathway.

c.5 Survey demographics

Subscription to Community Composting, LLC: Figure 3.26 shows the participation in the pilot waste-to-ethanol program, Community Composting, LLC. About half of survey respondents (47%) are currently participating in this program.

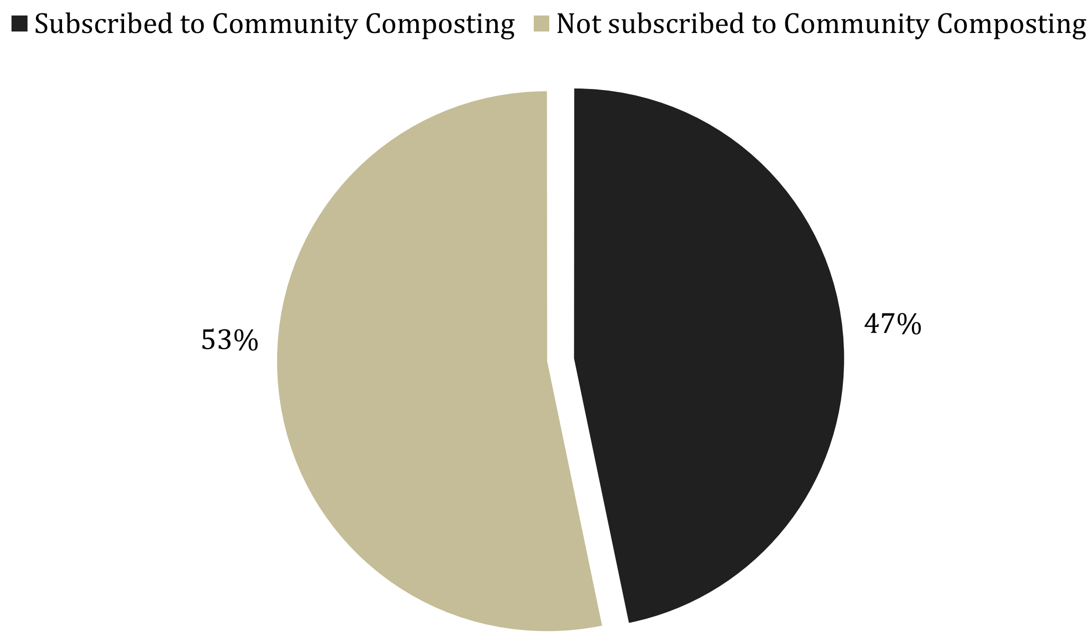


Figure 3.26: Subscribers to Community Composting, LLC among survey respondents (n=92)

Question #25 asked about the zip code in which the respondent lives. Figures 3.27.1 and 3.27.2 present the data broken down by Community Composting subscription status and city quadrant respectively.

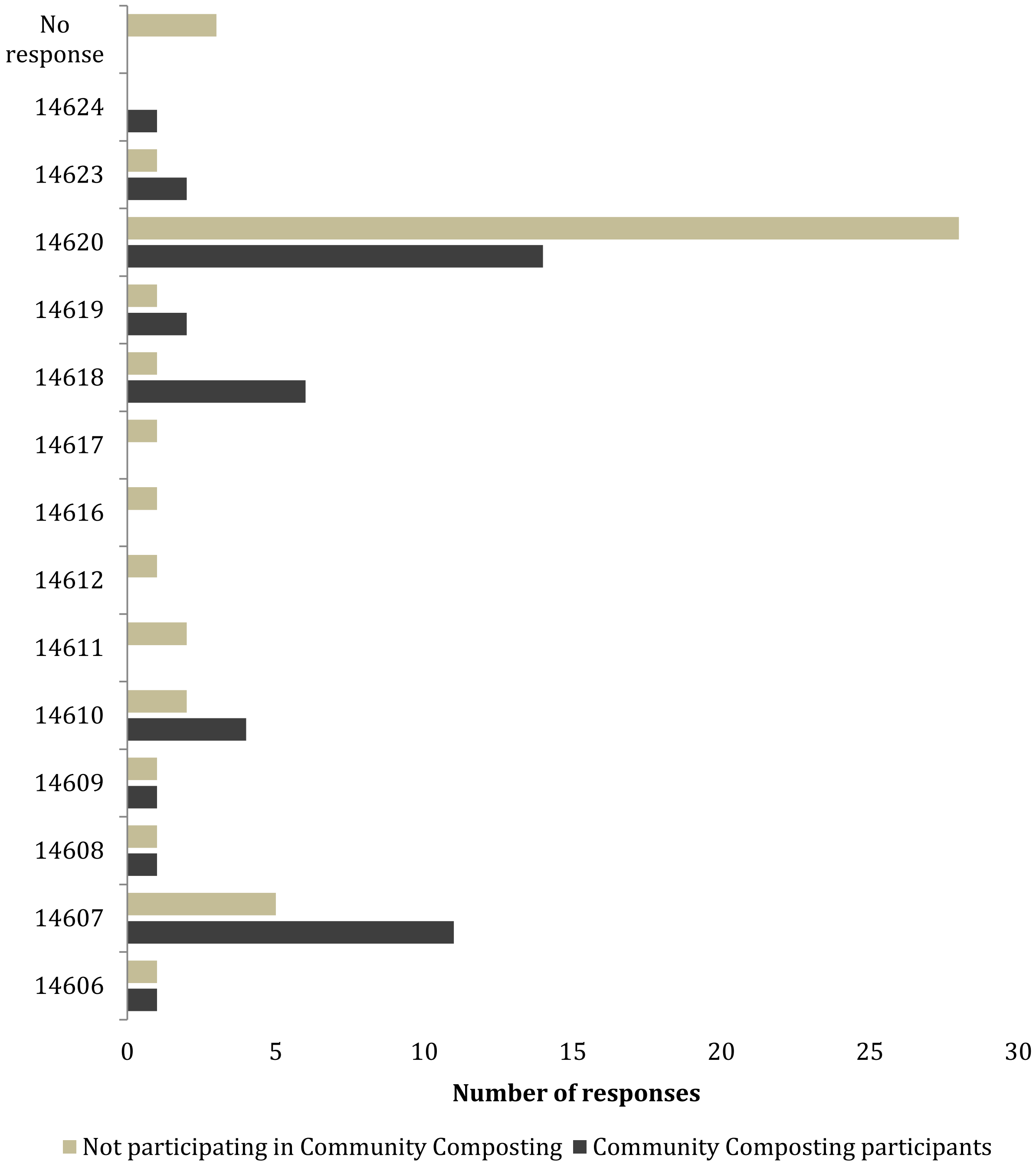


Figure 3.27.1: Zip codes of survey respondents, grouped by Community Composting subscription status

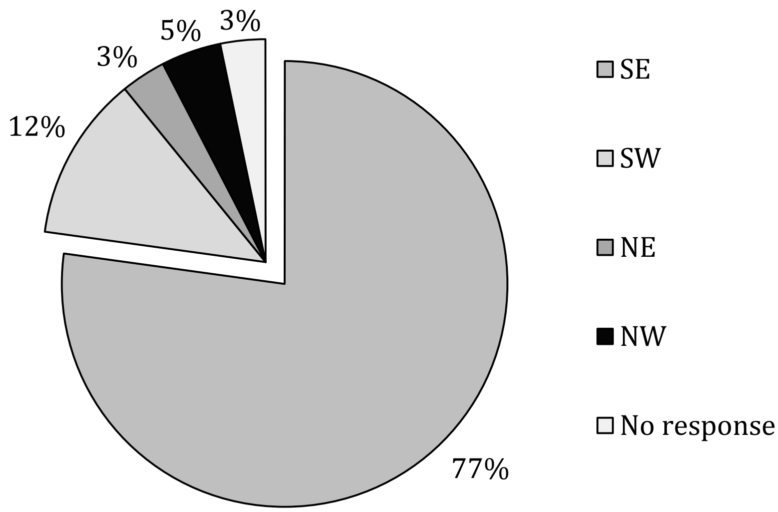


Figure 3.27.2: Zip codes of survey respondents, grouped by quadrant of the city (i.e. Northeast, Southeast, Northwest, Southwest)

Interpretation: The top four most frequently reported zip codes in the aggregate were 14620 (42 responses), 14607 (16 responses), 14618 (7 responses) and 14610 (6 responses). Outside of the top four, no reported zip codes exceeded 3 total responses. The top four zip codes (14620) are all located in the Southeast section of the city (see Appendix E) for zip code map of the city of Rochester, NY). Community Composting subscribers in the 14620 zip code were heavily represented in the survey (30% of the total). This zip code resides in the Southeast quadrant of the city. As Figure 3.27.2 shows, the Southeast was well represented in the survey, accounting for 77% of the respondents.

Question #26 asked about the gender identity of the respondents. Figure 3.28 shows the results.

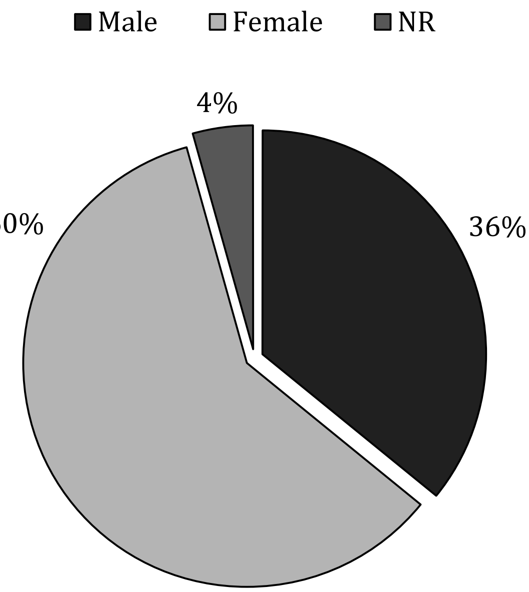


Figure 3.28: Gender identity of survey respondents

Interpretation: Female respondents significantly outnumbered male respondents. The high proportion of females subscribed to Community Composting (70%) contributed to this.

Question #27 asked about the racial and ethnic identity of survey respondents. The outcome is displayed in Figure 3.29.

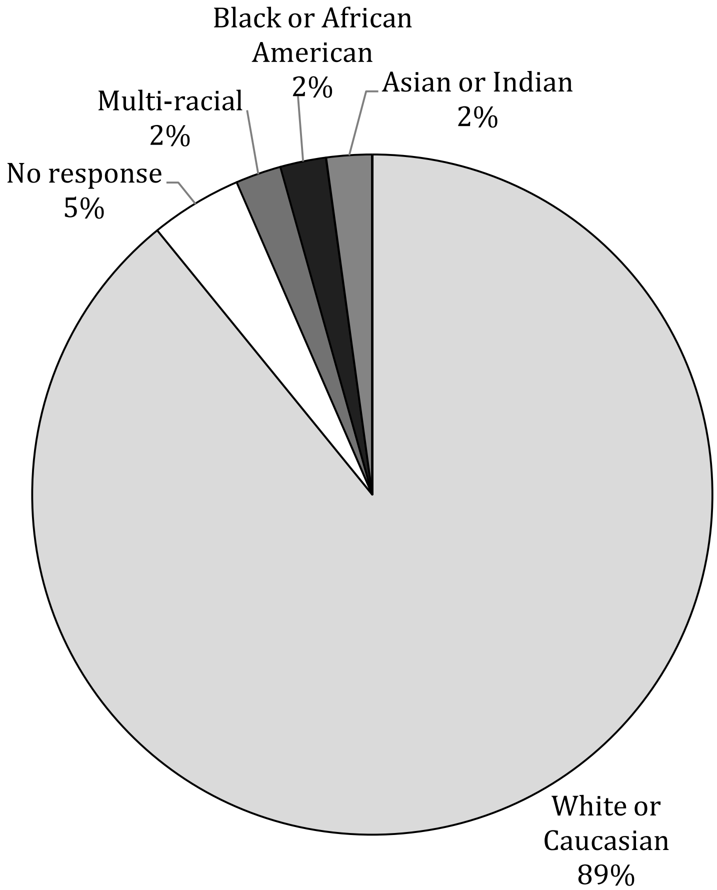


Figure 3.29: Racial and ethnic identity of survey respondents

Interpretation: Caucasian identity dominated the survey population (89% of total). Multi-racial, African American, and Asian or Indian had very small representation. Hispanic, American Indian, and all other ethnic/racial identities were not represented. This is problematic for generalizing the results to the entire city of Rochester, NY, considering that its current racial breakdown is 44% Caucasian, 42% African American, 3% Asian, 4% multiracial, and 7% all other races (United States Census 2010a).

Question #28 asked about the age of survey respondents. Figure 3.30 shows the results.

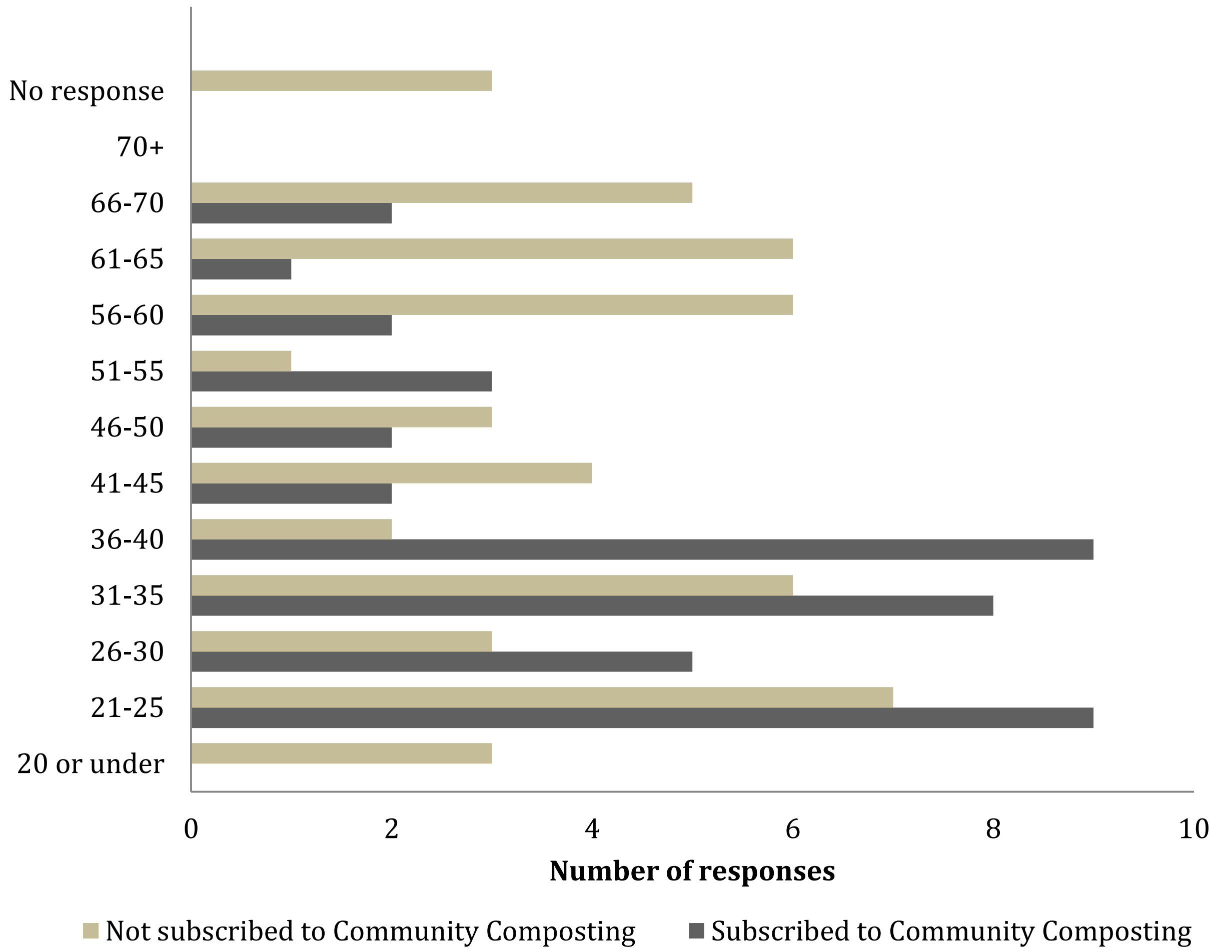


Figure 3.30: Age of survey respondents, grouped by Community Composting subscription status

Interpretation: In the aggregate, the top five age categories were 21-25 (17%), 31-35 (15%), 36-40 (12%), 26-30 (9%), and 56-60 (9%). About 28% of the respondents were over the age of 50 and 29% were below 30. About 8% of the survey respondents were over 65, which correspond to the 9% of the Rochester, NY population that is 65 or older (United States Census 2010a). People under 20 were likely underrepresented in this survey. They only made up 4% of respondents whereas 25% of the Rochester, NY population is under 18 (United States Census 2010a).

Question #29 asked about household income of the survey respondents. Figure 3.31 shows the results.

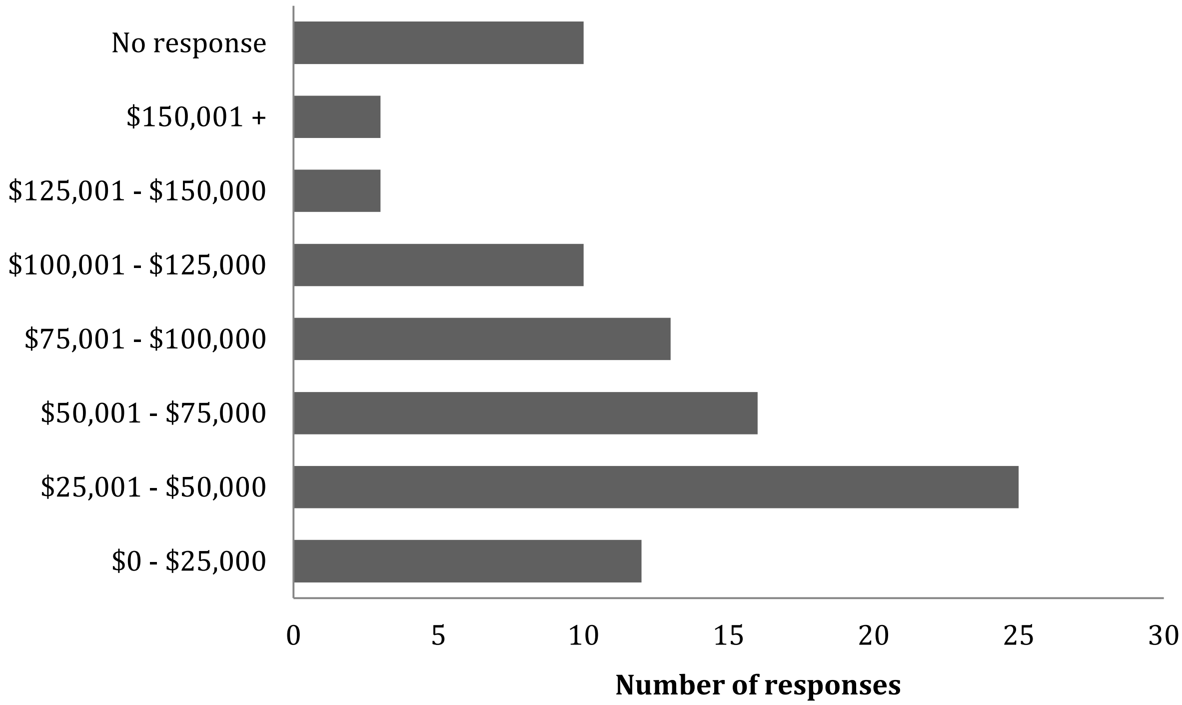


Figure 3.31: Household income of survey respondents

Interpretation: The respondents making between $25,000 and $50,000 had the highest proportion of respondents in this survey at 27%. Low-income residents were underrepresented in this survey. Responding households making under $25,000 constituted 13% of the survey population, while they constitute 42% of actual households in the city of Rochester, NY. Conversely, high-income residents were overrepresented in this survey. Responding households making over $100,000 constituted 17% of the survey population, while they constitute 8% of actual households in the city of Rochester, NY.

Question #30 asked whether respondents lived in single-family homes or multi-family dwellings. Figure 3.32 shows the results.

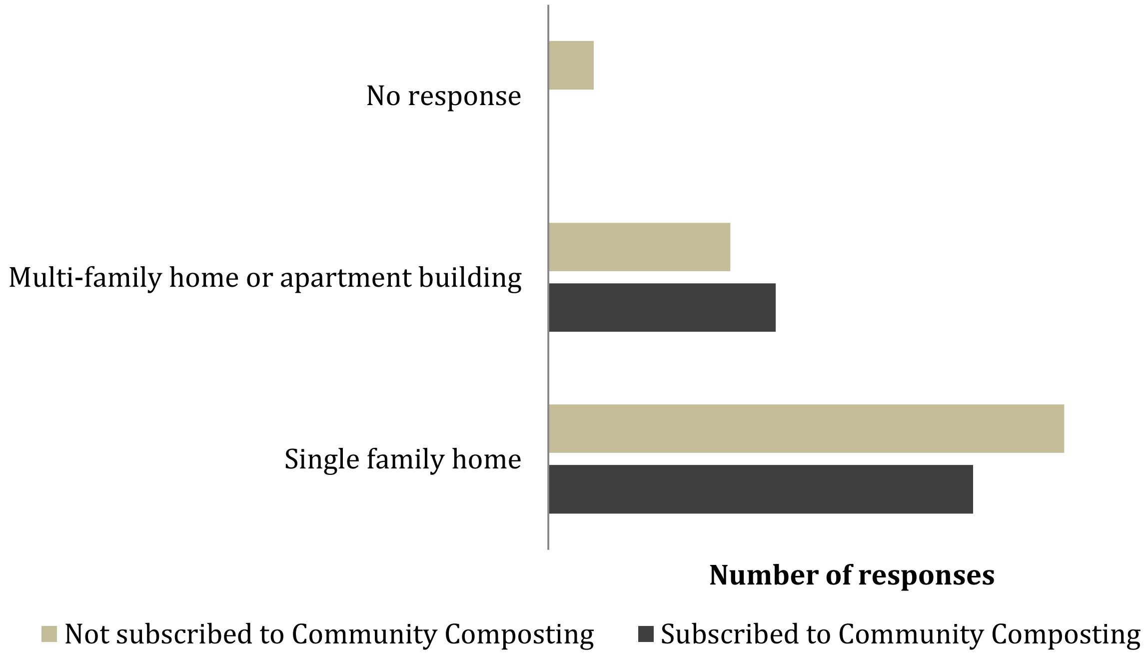


Figure 3.32: Household type (i.e. single-family or multi-family) of survey respondents, grouped by Community Composting subscription status

Interpretation: In the aggregate, 67% of respondents live in single-family homes, compared to 29% living in multi-family homes or apartment buildings. Single-family households are overrepresented in this survey – in the city of Rochester, NY, 49% of homes are single-family (i.e. 1-unit homes detached/attached) (United States Census 2010a). Among subscribers to Community Composting, 65% live in single family dwellings while 45% are in multi-family dwellings. A relatively high number of non-subscribers live in single family homes compared to those who are subscribed to Community Composting – although the difference is within the statistical margin of error.

c.6 Community Composting participation

This section explored the experience of residents subscribed to Community Composting, LLC – a subscription-based HHOM source separation program. This section was limited to current subscribers only.

Question #31 asked if subscribers had composted at home before joining. Figure 3.33 shows the results.

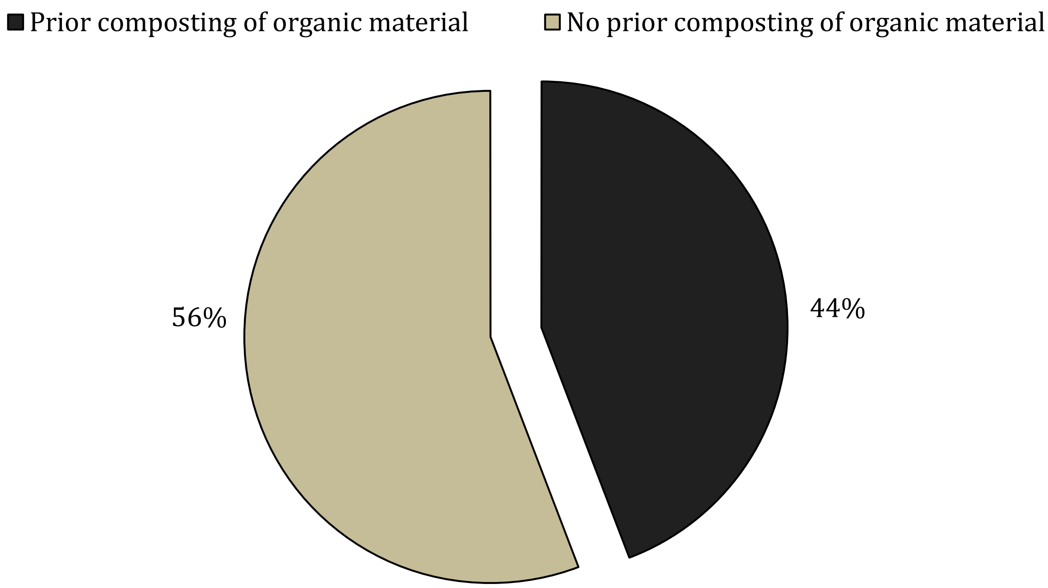


Figure 3.33: Home composting activity prior to subscribing with Community Composting, LLC

Interpretation: Subscribers' participation in home composting before joining Community Composting was less than half (44%). However, this indicates that many people were still willing to pay for curbside collection of household organic material in return for compost *even though* they already had everything that was needed to compost at home. This result suggests that the current presence of home composting may not be a significant barrier to curbside collection of household organic material.

Question #32 asked if subscribers were satisfied with their experience participating in Community Composting. Figure 3.34 shows the results.

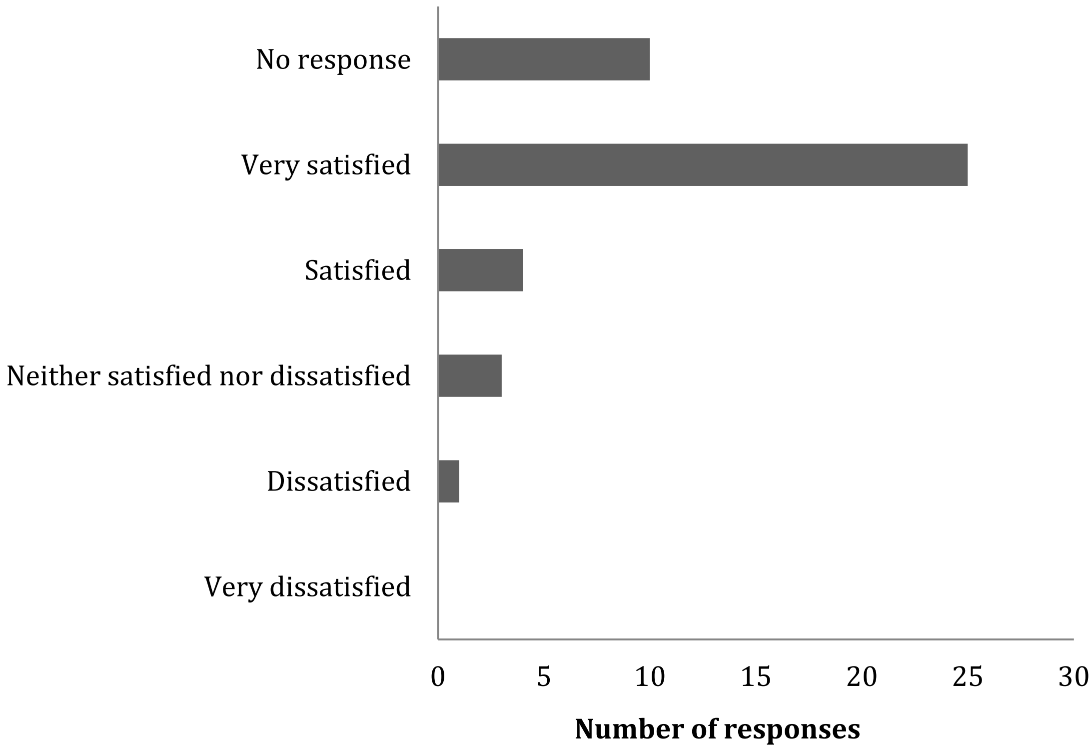


Figure 3.34: Overall satisfaction rating of Community Composting subscribers

Interpretation: A majority (58%) of subscribers are very satisfied by the Community Composting service. Only 9% of subscribers are less than satisfied. This may suggest that participating in the curbside collection of household organic material is a personally rewarding process.

Question #33 asked subscribers why they joined Community Composting. The following summarizes the main themes of the responses using samples from actual subscriber answers.

It was most common that subscribers wanted to benefit the community and the environment, and believed that utilizing household organic material was a great way to do so:

- “Heard about it being done in other cities and thought it was a fantastic idea.”
- “We previously lived in Berkeley, California and participated in city-run organic collection because it is important to us not to waste our food scraps (etc.).”
- “Formerly lived in a city where composting of yard waste, paper, and food was mandatory and found that most of my waste could be recycled or composted.”
- “Wanted to do something better with our food waste and get compost out of it.”
- “I wanted to do something else with my compost waste other than put it in a landfill.”
- “We wanted our resources used correctly instead of burying them.”
- “Because I felt it was the right thing to do for our environment.”
- “We could reduce organic material going to landfills and make sure useful products are derived from organic waste.”
- “I wanted to support an organization that was going to raise environmental awareness.”
- “Most of our garbage, we found out, was food waste (e.g., vegetable/fruit peels and pits, egg shells, meat fat) and paper towels.”

It was also very common that subscribers had faced barriers that prevented home composting (e.g. space, know-how, sanitation, etc.) and Community Composting subscription was a convenient alternative:

- “It's perfect for us because we have a tiny yard on a tiny lot in the city, so composting ourselves wasn't something realistic.”
- “I don't have to dump or wash buckets (nor do those jobs in a timely fashion--buckets build up fast).”
- “We were only occasional composters, it is much more reliable to do through this service.”
- “It was not very feasible to have a compost bin in the back in a multi-family building.”
- “Was less work and required less time than home composting.”

- “I was having vermin problems when I composted food waste in my home composter.”
- “It takes the stigma that my compost pile is the sole attraction for the undesirable critters of the city that my neighbors seem to have away.”

- “We were having problems related to our ongoing composting efforts, i.e. pests, etc. They were at the point where neighbors had complained. We strongly desired to continue composting but didn't know how to do it without exacerbating the problem.”

Some subscribers simply wanted to take the garbage out less often:

- “I love the convenience of having it picked up each week--and also taking out the garbage less often.”

Question #34 asked subscribers to list the problems they have had separating their household organic material for weekly collection by Community Composting. The following summarizes the main themes of the responses using samples from actual subscriber answers.

Some subscribers mentioned the smell of the material as a problem:

- “After a week, the smell is not great (Yes, keeping the lid sealed helps, until it's opened).”
- “Smell of compost is the worst problem - keeping the container away from our living space is a hassle.”
- “Limited ventilated space for the bin.”

Multiple respondents mentioned behavioral barriers to consistent household separation:

- “Remembering what I can compost is difficult.”
- “In the beginning it was hard to remember to use the bin.”
- “It is hard to remind others in the house to use the bin.”
- “Remembering to put out the bin (it would be great if it was the same day as trash day).”

The bin capacity was often mentioned as being too small, but buying another bin on the subscription is cost-prohibitive:

- “I probably won't have enough room in my compost bin from week to week, but paying for a second collection bin seems excessive, too.”

Question #35 asked subscribers about the benefits they have accrued from separating their household organic material for weekly pickup by Community Composting. The following summarizes the main themes of the responses using samples from actual subscriber answers.

The most commonly cited benefits were reduction of landfilled garbage quantity, improving the environment, and receiving compost:

- "Less garbage goes out each week! "
- "By diverting organic materials and recyclables, we produce very little landfill-bound waste."

- "Feeling like we are doing something important for the environment."
- "It feels better to know my waste is being utilized rather than thrown into a landfill."
- "I get peace of mind knowing that my organic materials are going to a good place and not languishing and leaching in a landfill."

- "I have access to locally produced compost for my gardens."
- "I'm looking forward to receiving kitchen plants and/or donating our compost shares."

Many subscribers mentioned reductions in smell from their trash, which offered vermin control:

- "Our kitchen garbage doesn't smell bad and we don't have to take it out very often."
- "We have fewer stinky garbage bags."

Subscribers mentioned logistical benefits to their household organic management:

- "Ability to compost dairy & meat which previously went into the trash since it can't go in our compost."
- "My trash does not attract vermin anymore."

Subscribers also mentioned social benefits (e.g. environmental awareness, educating others, greater enjoyment) by virtue of separating household organics:

- "We are more conscious of wasting food."
- "Having the bucket usually gets people to ask about composting. We got rid of the garbage can in our kitchen and now when people come over they have to stop and think."
- "Great way to teach our children another way to be kind to the environment."

-

- “It's fun and for a good cause.”
- “It's not only convenient, but it makes us very happy!”
- “I enjoy more thoughtful use of food (the bucket is in plain sight).”

Multiple subscribers noted health benefits:

- “I can see if I am eating right! The fuller the bin the better.”
- “We have an incentive to eat more produce versus pre-packaged meals.”

Question #36 asked subscribers whether or not their neighborhood interaction increased since subscribing. Figure 3.35 shows the results.

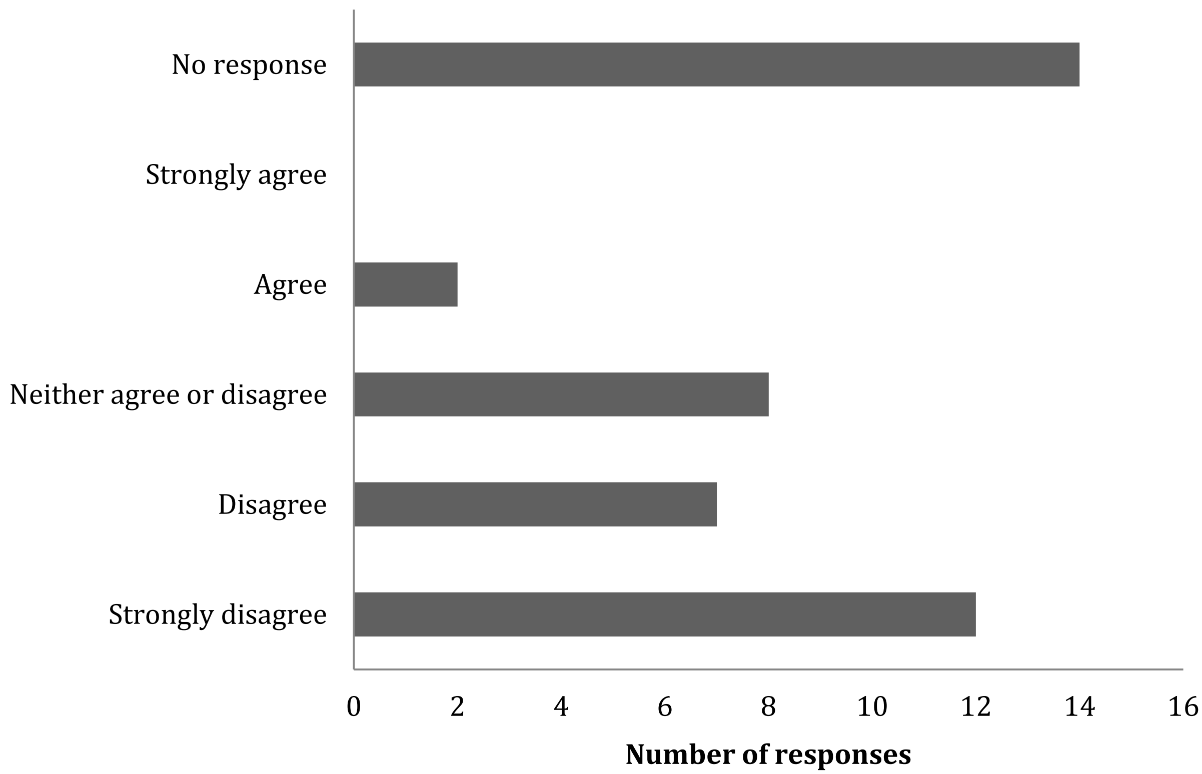


Figure 3.35: Community Composting subscribers’ agreement with the statement; "Since I began separating my organic material for collection by Community Composting, my level of interaction with my neighbors has increased.”

Interpretation: Among the 29 participants that responded, only 7% agreed that interaction with neighbors increased. On the other hand, 66% disagreed or strongly disagreed that interaction with neighbors increased. This suggests that participating in the Community Composting service does not increase social capital on its own.

c.7 Resident interviews

The interview results were mini-case case studies of resident perceptions and behaviors relevant household organic material management. Interview respondents self-selected to participate by reaching out to contact the author directly after taking the resident survey. A total of four interviews were conducted between October and November of 2013. Overall trends were:

1) Sustainable household organic material management can be an engaging activity on its own that attracts participants for recreational purposes (enjoy the process of source separation, home composting, and gardening)
2) Interest in organic material management came from prior experience living in a city with household collection or from food cultivation
3) Engagement in source separation of household organics enhanced resident awareness of the impacts of landfilling the material.
4) Respondents were new to the idea of paying for what material you throw out, but overall thought it was interesting. Multiple respondents commented on how it would be a more equitable solution than the current policy regime that would likely save material from going to landfill
5) The most prevalent terms that residents associated with “sustainable household organic material management” were job creation, creating a better world, and planning for the future.

d. Key findings

The key findings of the survey were that most residents in the Southeast section of the city of Rochester, NY have a positive willingness-to-pay for curbside collection of HHOM, implying participation if made available through a pay-as-you-throw MSW pricing project. The outlook for resident participation is strengthened by the finding that most residents would reduce their MSW output if they could save money by doing so (the main tenet of the pay-as-you-throw project). In addition, participants indicated a desire to avoid landfilling HHOM and to purchase locally produced energy and fertilizers produced from the material. One potential barrier is the lack of awareness about AD and SSF pathways as viable options for managing HHOM. Participants indicated that composting is the most well-known pathway and additional education is required to increase awareness of the others. Taken as a whole, the survey findings indicate that a HHOM management system utilizing non-landfill pathways can be socially sustainable under a pay-as-you-throw MSW pricing policy.

Chapter 4: Evaluating sustainable organic material management policy in Rochester, NY using cost-benefit analysis

a. Goals

The overall goal of this chapter was to estimate the monetary benefit to the City of Rochester from implementing a pay-as-you-throw (PAYT) household MSW pricing project. As discussed in Chapter 2, PAYT projects (also known as unit pricing or variable rate pricing) have a track record for effectively enabling both source reduction and source separation. PAYT projects have been able to solve a key issue to commercial development of organic material processing pathways (such as anaerobic digestion, SSF, and composting) by providing feedstock access (Skumatz and Freeman 2006; Miranda and Aldy 1998). When the pricing is set up so that household organic materials are picked up for free (either by the municipality or a commercial entity), households are often incentivized to separate the organic materials from their billed MSW stream (Skumatz and Freeman 2006; Miranda and Aldy 1998). In this way, PAYT projects can enable the expansion of diverse household organic material management pathways.

In this chapter the municipal and household budget impacts of implementing a weight-based PAYT with free HHOM collection were estimated using a cost-benefit analysis (CBA) set up in Microsoft Excel. Weight-based systems in particular are examined in this CBA because they more effectively lower household MSW generation than volume-based systems (Hong 1999) and have lower up-front capital costs (Hall et al. 2009). In this framework, municipal revenues and costs from implementing PAYT are the sum of household MSW collection revenues, avoided tipping fees, and avoided trucking costs, less the capital and administrative costs of the project. They include both tipping fees eliminated through MSW source reduction (i.e. less collected MSW) and fewer trucking hours to pick up MSW (i.e. less fuel and maintenance required). The municipal avoided costs have the same positive budget impact as municipal revenues earned. Thus in the CBA they were both counted as benefits compared to the baseline flat fee regime.

Net savings under PAYT were compared to total revenue of MSW collection currently received from city of Rochester households to get net municipal budget impact. Similarly, household budget impacts were determined by comparing current MSW collection costs to collection costs under the PAYT program. In addition to first-year budget impacts, the PAYT project net present value was calculated over the life of the project. The following sections show that the net present value (NPV) of implementing a weight-based PAYT project is $12,100,000-18,100,000 for the City of Rochester. The high NPV of the PAYT project compared to the baseline flat fee regime implies that policy intervention would help to maximize economic benefits from HHOM management. The following sections in this chapter provide an in-depth explanation of the CBA methodology and assumptions that led to these conclusions.

b. Methodology

b.1 Overview

The key consideration for achieving positive financial benefits from a PAYT program for MSW is setting a price that is acceptable to both residents and municipal decision makers (Hall et al. 2009). Without meeting the needs of both parties, the policy will be unacceptable. As such, optimum prices for the PAYT policy were defined where budget increases were achieved after a year of the unit pricing program relative to the current flat fee policy regime. An optimum PAYT price must ensure:

- A positive change in municipal budget (as defined in the previous paragraph), before capital and administrative costs;
- Maximum possible household municipal solid waste (HH MSW) collection revenue before capital and administrative costs, and;
- A positive change in average household budget

b.2 Assumptions for CBA of pay-as-you-throw policy implementation

In the CBA model, households were assumed to accept (and participate in) a PAYT policy with curbside collection that provides a budget increase. This was based on the survey and interview findings in Chapter 3 of this research, which indicated most residents are both likely to participate with a positive economic incentive and have a willingness to pay for HHOM collection service. Municipal budget impact must be positive in the absence of capital and administrative costs otherwise there is no situation in which the net present value of implementing the program can be positive. Municipal revenue is maximized in the CBA model because the municipality is most likely to finance the fixed costs and variable costs of running the program (and thus bear the risk).

When these criteria are satisfied, the PAYT program is considered viable and warrants further calculation of financial benefits over the 11 year project life. This number reflects the expected service life of the weighing machinery required for billing residents by the kg for MSW collection (i.e. “special industry machinery and equipment for local government” according to the Bureau of Economic Analysis) (Bureau of Economic Analysis 2014). Cumulative financial benefits to the City of Rochester were calculated with and without discounting.

Revenues

Municipal budget impact from implementing a PAYT household MSW pricing program was calculated as the difference between current household MSW collection revenues brought in by the City of Rochester, and the sum of expected collection revenues and avoided costs under PAYT. For the flat fee MSW pricing policy (*status quo*), service revenue was calculated by multiplying the MSW collection fee of $343 per household (City of Rochester, NY 2014b) by the 86,150 households in the city of Rochester, NY (United States Census 2010b). Under PAYT, MSW collection service revenue was found by multiplying the unit price ($/kg) by the amount of MSW put out for municipal collection. Household budget impacts were calculated based on the difference of what is being paid now ($343) and what would be paid under PAYT – that is household MSW generation times MSW price. Household MSW generation was found by dividing MSW (after source reduction; see section x for calculation) by the number of households in the city of Rochester, NY.

Avoided costs

Part of the avoided costs from the PAYT program are from reduced landfill tipping fees on a $/kg basis. Landfill tipping fees were assumed to be $60/ton or $0.066/kg (Waste Management 2013c). Avoided landfill tipping fees were calculated by multiplying tipping fees ($/kg) by the difference between MSW generation under the flat fee regime (100% of which is assumed to go to the landfill) and the estimated MSW generation under PAYT (see Figure 4.2 for graph of MSW generation under PAYT; Tables 4.1 and 4.2 for trucking cost assumptions; and Appendix G for detailed data and parameters for calculating MSW generation). In the case of private sector organic collection, avoided tipping fees were always greater since it was assumed that municipal collection would send the material to the landfill, whereas private collection would send it to other pathways such as anaerobic digestion, composting, and SSF. This assumption is verified by the baseline private sector profit maximization model results in Chapter 5. Organic collection could be assumed to be free since the profit-maximizing pathways remain the same even in the absence of tipping fee revenue.

The other component of avoided costs is avoided trucking costs. Avoided trucking cost values are equivalent to the difference between trucking costs under the current flat fee regime and PAYT. Flat fee regime trucking costs were assumed equivalent to the city household MSW collection fee multiplied by the number of households in the city of Rochester, NY. In order to calculate PAYT trucking costs, first the daily expense for a tipper truck with a 24 short ton capacity (i.e. 21,772 kg) was tabulated using a FreightMetrics tool kit available online (FreightMetrics 2014). See Table 4.1 for full parameter assumptions used in the FreightMetric tool. It was assumed that the trucks would be running 6 days per week, 52 weeks per year – that is 312 days per year. MSW generation per collection day was found by taking total MSW generation and dividing by truck running days. From there, this number was divided by truck capacity to get trucks needed per collection day. By multiplying cost per truck, trucks per day, and the number of running days per year, the annual trucking cost was found. The general equation below shows the avoided trucking cost calculation, and Table 4.2 displays its baseline assumptions:

$$
\begin{aligned}
&\mathit{Annual\ avoided\ MSW\ collection\ trucking\ cost} \\
&\qquad = (\mathit{household\ collection\ fee}\ (\$) \times \mathit{households\ in\ the\ city\ of\ Rochester}) \\
&\qquad - \left(\frac{\$}{\mathit{truck\ collection\ day}} \div \frac{\mathit{truck\ capacity}\ (kg)}{\mathit{collection\ day}}\right. \\
&\qquad \left. \times \frac{\mathit{total\ MSW\ generated}\ (kg)}{\mathit{total\ collection\ days}} \times \frac{\mathit{collection\ days}}{\mathit{year}}\right)
\end{aligned}
$$

Table 4.1: Parameter assumptions for trucking costs in FreightMetrics tool (FreightMetrics 2014)

Adjustable parameter in FreightMetrics	Value
Miles/ day	70
Driver wage ($/day)	130
Depreciation rate	5.00%
Interest rate	8.00%
Diesel price ($)	4.16
Truck type	Single tipper
Truck capacity (short tons)	24
Truck capacity (kg)	21,772.4
$/truck/day	691.83

Table 4.2: Baseline trucking cost assumptions for flat fee regime

Parameter	Value
Residential MSW generated (kg)	96,652,974
MSW collection flat fee ($)	343
Trucks needed per MSW collection day	14.23
Truck charge per day ($)	8,414
Truck charge per year under flat fee program ($)	2,625,246
MSW collection days per year	312

Source separation rate

The source separation rate is an assumption that has an effect on the municipal savings that could be achieved through private collection of household organic material. The price of PAYT has a greater effect on source *separation* of recyclable materials (e.g. food, yard trimmings, compostable paper, glass, metals, etc.) and a much lesser effect on source *reduction* of overall MSW (Skumatz and Freeman 2006; Miranda and Aldy 1998). The strong effect of PAYT on source separation prompted the assumption of a 100% source separation rate for the CBA. PAYT systems paired with aggressive recycling programs (such as the one modeled here) perform better at inducing household source separation than ones without them (Hong 1999). While perfect source separation behavior is not possible to attain, 100% source separation was assumed to show the budget impacts assuming a high participation rate common to PAYT programs (Skumatz and Freeman 2006). The CBA has a built-in sensitivity analysis that accounts for the effect of source separation rates on municipal budgets. This is achieved by having wide-ranging high, mid, and low source reduction estimates. Source reduction has a similar impact on revenues as source separation – in both cases material is offset from the MSW stream that the municipality hauls to the landfill and bills residents for.

Other factors

Although household MSW generation is a function of price, the MSW price is not the only factor influencing source reduction under PAYT. Mean level of income, the share of homeowners, the age distribution, the average number of people in a household and other demographic variables have an effect (Fullerton and Kinnaman, 1996). However, these variables are out of the direct control of the municipality and were not considered in this CBA model.

b.3 Accounting for key controlling indicators by setting up scenarios

The PAYT program CBA assesses municipal and household budget impacts under various combinations among three controlling parameters (or indicators):

- induced MSW source reduction behavior: 3 options (high; mid; low)
- unit pricing base charge: 2 options (high = $15; low = $0)
- organic collection provider: 2 options (municipal; private)

The CBA analyzed twelve scenarios (3 x 2 x 2 options) in total, all of which are shown in Table 4.3. The complete rationale of scenario definition, selection, and calculation are explained in the following sections of this chapter.

Table 4.3: Cost-benefit analysis scenarios for weight-based pay-as-you-throw policy implementation

CBA Scenario number	Source reduction behavior	PAYT base charge	Organic collection provider
1	High	High	Municipal
2	High	High	Private
3	High	Low	Municipal
4	High	Low	Private
5	Mid	High	Municipal
6	Mid	High	Private
7	Mid	Low	Municipal
8	Mid	Low	Private
9	Low	High	Municipal
10	Low	High	Private
11	Low	Low	Municipal
12	Low	Low	Private

Calculating budget impacts at the optimum price for each scenario

For each of the 12 scenarios, PAYT prices were plotted in Microsoft Excel from \$0.00 to \$3.00 (a feasible price range based on published values in Table 4.4). Revenues and costs were calculated at MSW price intervals of \$0.01/kg. Under each of the 12 scenarios, municipal and household budget impacts were calculated relative to the status quo flat fee program. Optimum points were selected for further analysis over the life of the project. For a given scenario, the optimum MSW price was where municipal budget impact was maximized and household budget impact was positive.

b.4 Model development

Key indicators

<u>Annual base charge parameter</u>

Many municipalities implementing PAYT programs will have an additional annual base charge on top of the billed weight of MSW collected from households. Decision-makers implementing this project in the city of Rochester, NY will benefit from knowing whether or not a small base charge will increase project value. Although a base charge may seem like it will always positively increase municipal budgets, this is not the case. In the CBA, base charges lower average household budgets by an amount equivalent to their face value. Thus, residents accept a lower MSW price ($/kg) so that they will not incur a net household budget loss.

Organic collection provider

Free collection of household organic material offers residents the chance to reduce their municipal collection bills, thereby often incentivizing source separation of the material. This CBA framework assumed two organic collection scenarios: 1) free private sector collection and; 2) municipal collection in the regular MSW stream with no source separation. Although both methods are implemented for HHOM management, the literature indicates that municipal collection is slightly more common than private collection, especially in Europe. The private sector was assumed to collect the material for free because of its high value to processors. Free collection of household organic material would be a logical supplement to a PAYT policy where residents are paying by the kg for material they put out. Private sector actors would feasibly allow free pickup because they would want to ensure a healthy economic incentive for residents to source separate the material. If residents were also being charged for organics collection, the incentive to source separate from their regular MSW stream would be diminished. Consistent source separation ensures stable feedstock access, which is critical in the organics processing business. The municipality was not assumed to collect source separated household organic material because they are not currently doing so.

Source reduction behavior

In order to realistically represent budget impacts with a CBA, it was required to take into account the induced municipal solid waste source reduction behavior brought on by household responses to paying a price to discard material. Studies have shown that higher PAYT prices lead to household MSW collection demand reduction via: 1) increased source separation behavior (Miranda and Aldy 1998) and; 2) MSW generation reduction (Skumatz and Freeman 2006; Su et al. 2010).

Source reduction directly impacts municipal revenues, private sector profits (i.e. access to material for AD, SSF, and composting), and household budgets. As households reduce what they throw away to lower their MSW collection bill, municipal revenues decline. On the other hand, less MSW means municipal cost avoidance from fewer trucks on the road and reduced municipal tipping fee payments at the landfill.

Calculations

Source reduction behavior estimate

This cost-benefit analysis of weight-based pay-as-you-throw policy takes into account the impacts of MSW collection price ($/kg) on source reduction behavior, as measured by demand for MSW collection. Demand for curbside collection of source separated organic material is a proxy indicator for household organic material source separation rate. Lower demand for MSW collection service means more material is separated out for re-use in pathways such as anaerobic digestion, SSF, and composting instead of traveling to landfills with unsorted MSW.

The curves describing source reduction behavior (Figure 4.2) were composed of United States and global data on: 1) observed first-year reductions in PAYT programs (Table 4.4) and; 2) residents' source reduction response to price increases under established programs (Table 4.5). More source reduction is expected in the first year of a PAYT project (before exposure to source reduction incentive) as opposed to later years.

Normally, a curve would be generated from the published literature on newly implemented programs to establish expected generation under different MSW prices. However, there is no statistically significant correlation between first-year prices and source reduction using published values (R^2=0.1429) (see Figure 4.1; Table 4.4). As such, to determine the percent reductions to apply to MSW generation at each price before the $1.60/kg tipping point, the responsiveness of MSW generation to $/kg unit price was calculated from the literature (see results in the column titled "% MSW reduction per $ unit price" in Table 4.4).

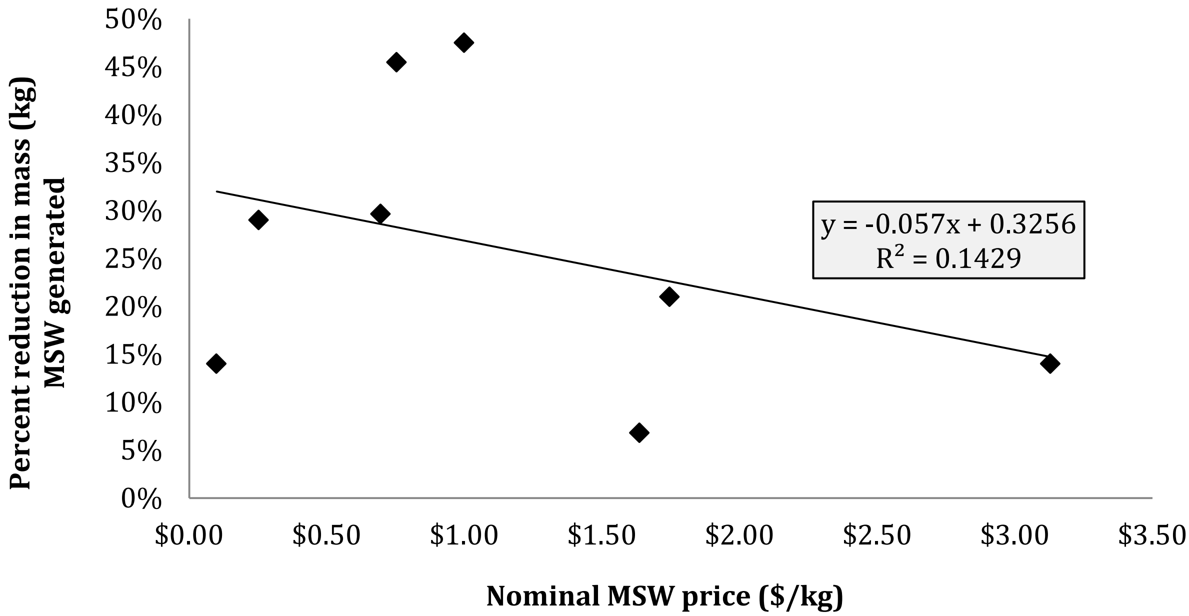


Figure 4.1: Relationship between MSW price and percent reduction in mass (kg) of MSW generated from published literature

For each case from the literature (Table 4.4 below), responsiveness of MSW generation to a new unit price was calculated by dividing the total observed percent MSW reduction by the unit price implemented. The high source reduction outcome utilized the data from County of Aschaffenburg, Germany – i.e. 41% reduction in MSW per $ unit mass charge. The most drastic observed MSW generation reductions (Charlottesville, Virginia, US and Tvååker, Sweden) were not used in the analysis, because they projected negative MSW generation before the $1.60/kg tipping point price was reached. The mid source reduction scenarios – 30% reduction per $ unit mass charge – were pulled from the 21-city average of nascent unit pricing programs from Miranda et al. (1994). The low source reduction scenarios – 2.5% reduction per $ unit mass charge – are based on data from Portland, Oregon determined by Bauer and Miranda (1996).

Table 4.4: Percent MSW generation mass reduction (i.e. source reduction) from newly implemented unit-pricing (PAYT) programs

Location	Date	Observed MSW mass source reduction (%)	MSW reduction (% per $ inflation-adjusted MSW price)	Inflation-adjusted price ($/kg)	Nominal price ($/kg)	Source
Charlottesville, Virginia, US	1992	14%	83%	0.17	0.10	Fullerton and Kinnaman 1996
Tvååker, Sweden	1994	29%	73%	0.40	0.25	Sterner and Bartelings 1999
County of Aschaffenburg, Germany	1997	45%	41%	1.10	0.75	Bio Intelligence Service 2012
21 cities (average)	1994	48%	30%	1.60	1.00	Miranda et al. 1994
Oostzaan, Netherlands	1993	30%	26%	1.15	0.70	Linderhof et al. 2001
San Jose, California, US	1994	21%	7.5%	2.78	1.75	Bauer and Miranda 1996
Torrelles de Llobregat, Spain	2003	14%	3.5%	4.01	3.13	Puig-Ventosa 2008
Portland, Oregon, US	1992	7.0%	2.5%	2.76	1.64	Bauer and Miranda 1996

MSW generation for MSW prices below \$1.60/kg tipping point

Using these assumptions, estimated MSW generation under the newly implemented unit pricing program was calculated by taking current MSW generation in Rochester, NY under the flat fee regime and subtracting the expected change in generation at a given price. Expected change in generation is the product of resident source reduction responsiveness (i.e. %MSW reduction per \$/kg unit price), unit price (\$/kg), and current MSW generation in Rochester, NY). The general calculation for total MSW generation is below:

$$MSW\ generation\ \left(below\,\frac{\$1.00}{kg}\right) = Rochester\ current\ MSW\ generation\ (kg) - \left[\frac{Unit\ price\ (\$)}{kg} \times \frac{\%\ MSW\ reduction}{Unit\ price\ (\$)} \times Rochester\ current\ MSW\ generation\ (kg)\right]$$

MSW generation for MSW prices above \$1.60/kg tipping point

Above the \$1.60/kg price – at which the steep MSW generation reductions of a newly implemented program begin to stagnate – price elasticity of demand (PED) data for MSW collection in established unit pricing programs was used (published data in Table 4.5). PED is a measure of consumer price responsiveness, precisely the percent change in quantity demanded divided by the percent change in price. Here PED is assumed to be constant, with a continuous strictly quasiconcave demand for MSW collection services (i.e. MSW generation will never be zero at a high price). MSW generation at the final MSW price is calculated by adding the product of MSW generation at initial price, percent change in price, and price elasticity of demand for MSW disposal services to MSW generation at initial price. The general calculation is for MSW reductions using price elasticity of demand is below:

$$MSW\ generation_f\ (kg) = MSW\ generation_i\ (kg) + \left(MSW\ generation_i\ (kg) \times \frac{Unit\ price_f\left(\frac{\$}{kg}\right) - Unit\ price_i\left(\frac{\$}{kg}\right)}{Unit\ price_i\left(\frac{\$}{kg}\right)} \times \frac{\%\Delta\ MSW\ generation\ (kg)}{\%\Delta\ \text{Unit price}\left(\frac{\$}{\text{kg}}\right)}\right)$$

Price elasticity of demand data selection

For high source reduction scenarios, the second highest PED in the data set entered the calculation (-1.39). The upper bound (-4.00) was not used because it would result in an increase in MSW generation after the tipping fee price. In addition, it is nearly three times higher than the second highest value, which indicates that it is an extreme value that is not likely to occur in Rochester, NY. The mid source reduction scenarios used the average (-0.49) and the low source reduction scenarios used the lower bound (0.00).

Table 4.5: Price elasticity of demand for MSW disposal service under unit-pricing programs

Study	Country	Own-price elasticity of demand
Household surveys		
Hong et al. (1993)	USA	0.00
Van Houtven and Morris (1999)	USA	-0.10
Van Houtven and Morris (1999)	USA	-0.26
Fullerton and Kinnaman (1996)	USA	-0.08
Hong (1999)	Korea	-0.15
Linderhof et al. (2001)	The Netherlands	-1.39
Linderhof et al. (2001)	The Netherlands	-0.34
Aggregate municipality data		
Wertz (1976)	USA	-0.15
Jenkins (1993)	USA	-0.12
Strathman et al. (1995)	USA	-0.45
Van Houtven and Morris (1999)	USA	0.00
Kinnaman and Fullerton (1997)	USA	-0.19
Podolsky and Spiegel (1998)	USA	-0.39
Van Houtven and Morris (1999)	USA	-0.15
Kinnaman and Fullerton (2000)	USA	0.00
Dijkgraaf & Gradus (2004)	The Netherlands	-4.00
Average		-0.49

Calculated MSW generation for each MSW price is shown in Figure 4.2. MSW generation is a function of MSW price and the severity of expected source reduction behavior at that MSW price. Note that after the $1.60/kg point, MSW generation reductions begin to stagnate. Miranda et al. (1994) conducted a study of 21 cities that had newly implemented PAYT programs, and determined that $1.00/kg is a tipping point price, after which source reduction begins to stagnate. Adjusting for inflation to 2014 (Bureau of Labor Statistics 2014b), the real price is $1.60 for the tipping point. The $1.60/kg price is the endpoint for the steeper source reduction behavior response of residents under newly implemented PAYT. Prices higher than $1.60/kg utilize source reduction behavior data under well-established PAYT programs. MSW generation reductions in response to price elasticity of demand are what would be expected with an established unit pricing program where consumers have been exposed to a unit price for unsorted MSW. Over $1.60/kg, increasing MSW price reduces MSW generation based on published price elasticity of demand for MSW collection services (Table 4.5).

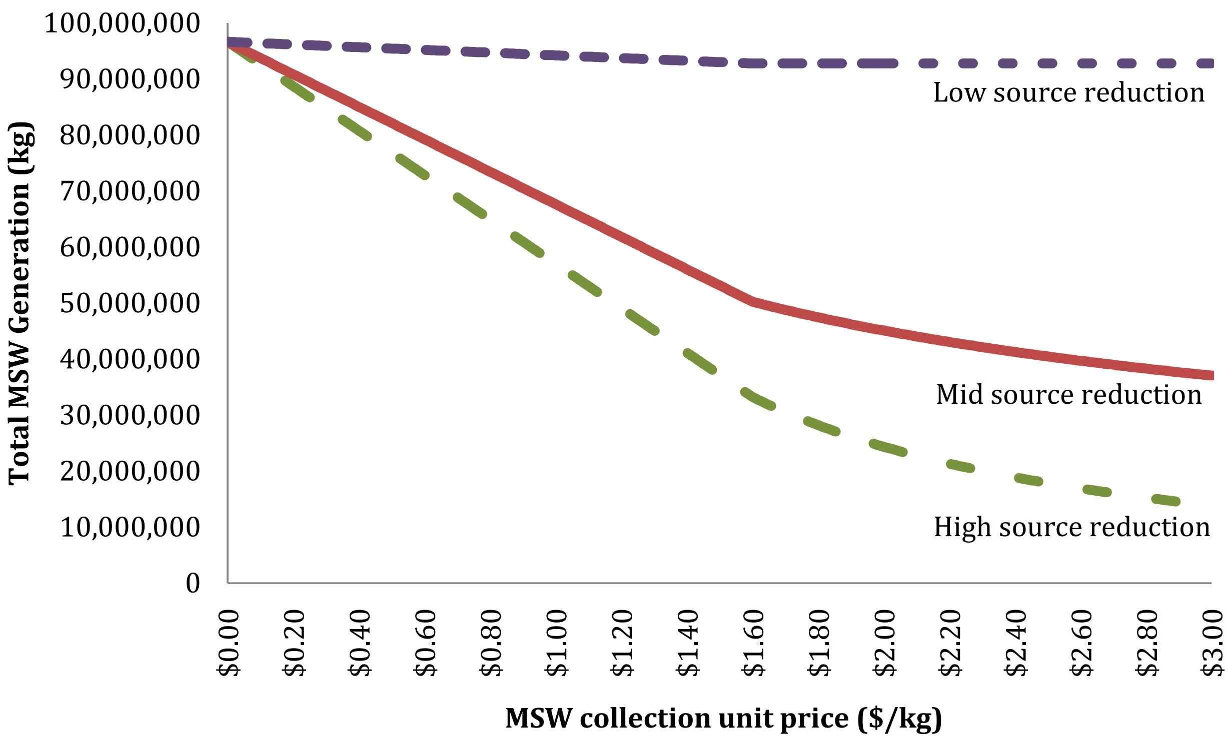


Figure 4.2: Estimated household MSW generation (kg) high, mid, and low source reduction scenarios for all prices for unsorted MSW ($/kg)

PAYT project value

First-year break even value of capital and administrative costs under 12 scenarios

Municipal projects that operate under very tight fiscal constraints require positive cash flows from the beginning of the project. As such, it was important to find the PAYT project benefits over the first year to determine a break-even value for project costs. The break-even value of capital and administrative costs for the first year of project implementation was calculated as the sum of municipal revenues and avoided costs under PAYT.

Net present value of project under 12 scenarios

In order to accurately reflect the costs and benefits of the PAYT project at the optimum points, total benefits and net present values were calculated assuming an 11-year project life (Table 4.8). Not every optimum point was used in this step – one scenario with maximum municipal budget impact was chosen from each level of source reduction. This was done because source reduction has the biggest influence on the model, and is out of the control of decision-makers. Picking three key points at each level of source reduction that maximize municipal budget impact automatically selects the best arrangement of annual base charge and organic collection provider (program aspects that decision-makers can control). Cash flows were calculated over each year of the project to inspect whether the project has negative cash flows that could be unacceptable for a municipality with the tightest fiscal constraints.

As with any new material management program, additional capital and administrative costs apply to PAYT (i.e. weighing equipment, record keeping, billing support, extra city sanitation code enforcement). Table 4.6 below shows the capital and administrative costs derived from published literature that were applied in the CBA. In order to derive total costs over the project life, PAYT capital and administrative expenses were taken from case study cities and scaled to the city of Rochester. This was done by dividing by the number of households served by the program in another city to get cost per household. The estimated capital and administrative cost to serve all city households is the product of the cost per household and the number of households in the city of Rochester, NY. Midpoint cost estimates were used throughout the CBA.

The NPV calculation amortized payments for capital costs over 11 years, assuming interest rates of 3.22% and 9.66%. Recurring administrative costs were also taken into account. The net benefit of PAYT on municipal budget was calculated excluding capital and administrative costs. This means that net benefit is equivalent to the break-even capital and administrative costs for the year of implementation (displayed in Table 4.7).

Table 4.6: Estimated unit pricing program capital and administrative costs ($) (baseline CBA inputs)

Description	Cost per household ($/HH)	Cost to serve city of Rochester, NY ($)	Case study city; reference
Capital costs			
Lower bound	14.38	1,238,461	Milwaukee; (Hall et al. 2009)
Upper bound	43.56	3,752,913	Milwaukee; (Hall et al. 2009)
Administrative costs			
Lower bound	3.40	292,910	San Jose; Bauer and Miranda 1996
Upper bound	6.38	549,637	Flint; Bauer and Miranda 1996
Total costs			
Lower bound	17.78	1,531,371	Milwaukee; (Hall et al. 2009); San Jose; Bauer and Miranda 1996
Upper bound	49.94	4,302,550	Milwaukee; (Hall et al. 2009);Flint; Bauer and Miranda 1996
Midpoint	33.86	2,917,039	Milwaukee; San Jose; Flint; Hall et al. 2009; Bauer and Miranda 1996

c. Results and discussion

c.1 Household municipal solid waste collection revenue to the City of Rochester, NY

Household MSW source reduction behavior has a direct effect on the municipal collection revenue under unit pricing, since households are charged by the kg. Figure 4.3 shows the municipal revenue under different source reduction scenarios. Holding organic collection type constant, lower amounts of source reduction means that more MSW is picked up by municipality and more revenue is earned. Interestingly, at the greatest levels of source reduction, municipal revenues no longer increase with increasing unit prices. In the high source reduction scenario the price of $1.22/kg is an inflection point after which municipal revenues begin to decline with increasing prices – indicating that MSW generation is too low to increase revenues with a higher unit price (Figure 4.3).

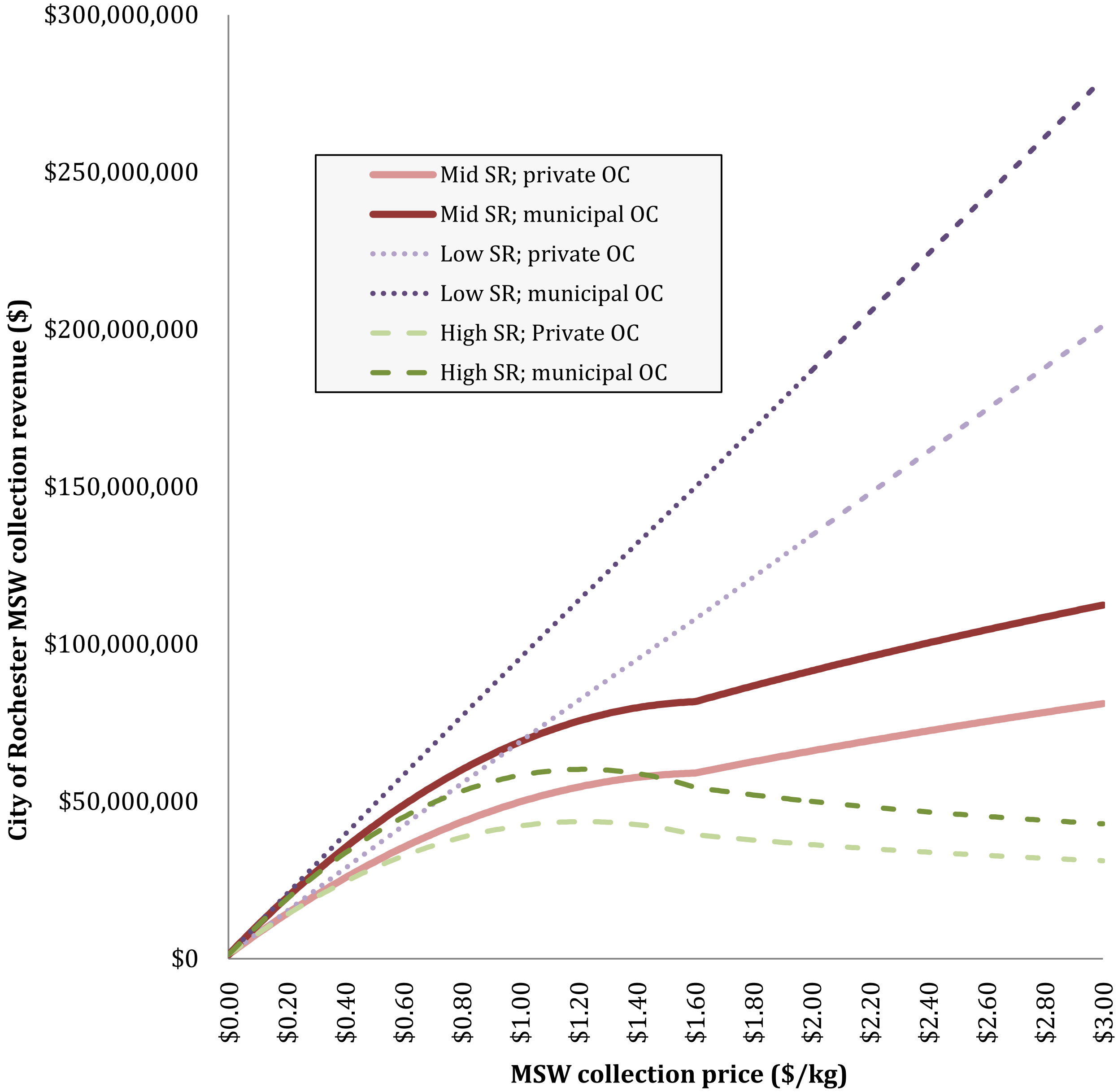


Figure 4.3: Predicted City of Rochester MSW collection revenue under pay-as-you-throw MSW pricing program: assuming high, mid, or low source reduction (SR); private sector or municipal organics collection (OC); $15 base charge

c.2 Municipal budget impacts under pay-as-you-throw program

The municipal budget impact of PAYT (for now excluding capital and administrative costs) is negative at the lowest prices. The budget impacts are negative until a high enough mass of household municipal solid waste (HHMSW) is collected to exceed current flat fee revenues. This break-even point occurs at the lowest prices in the low source reduction scenarios. Low source reduction yields the highest potential budget impacts, due to the much higher mass of material being charge the unit price. However, municipal budget gains are not feasible when they would cause a reduction in average household income, and thus be politically unacceptable. Thus, this makes it unlikely that such high-impact programs under the low source reduction scenarios could be implemented. In addition, low source reduction is undesirable from an environmental standpoint. The positive budget impact increases steadily through $3.00/kg in the mid source reduction scenario. The low source reduction scenario peaks near $20,200,000 and declines due to declining amounts of material collected from high MSW prices.

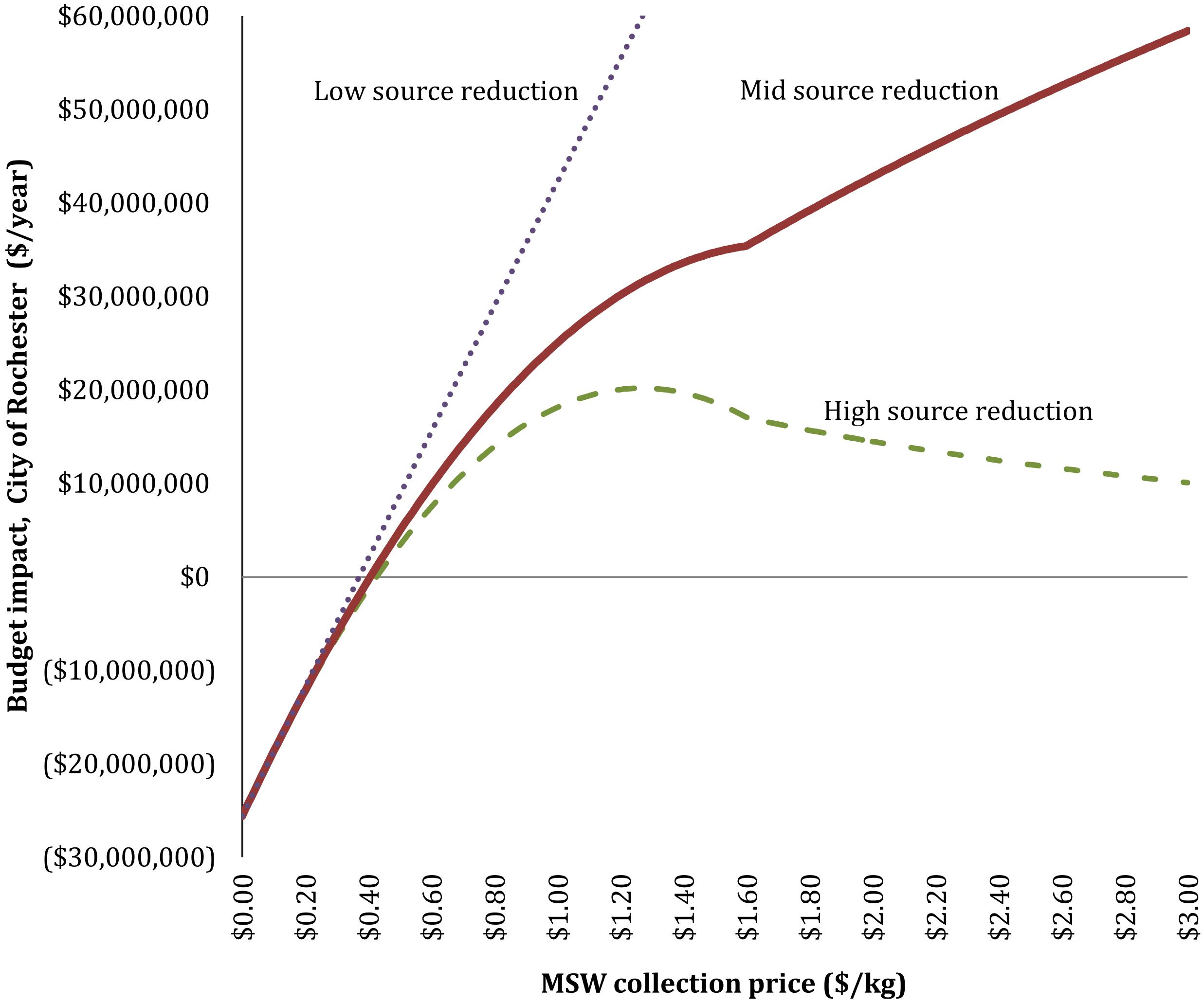


Figure 4.4: Predicted first year budget impact on City of Rochester, NY under pay-as-you-throw MSW pricing program under different scenarios: high, low, and mid source reduction (SR); private sector organic collection; $0 annual base charge

c.3 The effect of private sector organic collection on municipal budget

Figure 4.5 shows the effect of free private organic collection on municipal MSW collection revenue. By allowing private firms to collect source separated organic material free of charge, there is less mass of MSW for municipal collection, thereby further reducing revenues. Private organic collection stands on its own merits as a way for the city of Rochester, NY to positively impact its HH MSW collection budget. At the current level of MSW generation in the absence of source reduction (which is equivalent to MSW generation at a price of $0.00) private sector collection of all household organic material will result in $2,700,000 of avoided trucking costs and landfill tipping fees for the municipality. This is based solely on avoided costs of trucking ($900,000) and landfill tipping fees ($1,800,000). Figure 4.5 shows how the value of private organic collection changes relative to the unit price for MSW ($/kg) under different source reduction scenarios. The higher the amount of expected source reduction behavior, the lower the municipal budget impact of private organic collection. This is due to the lower annual mass of HH organic material generation.

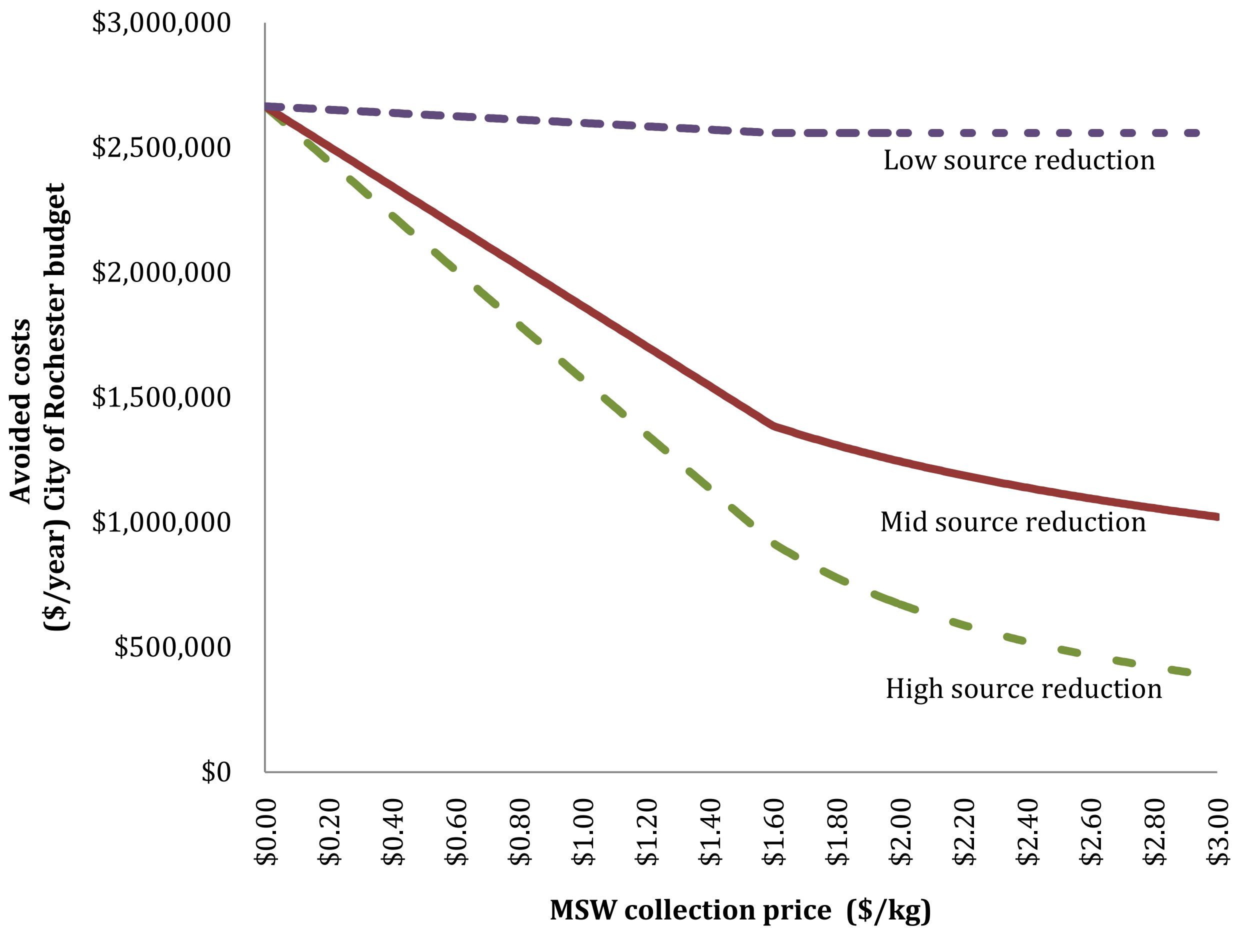


Figure 4.5: Predicted City of Rochester budget impact from avoided operating costs via private sector household organic material collection under pay-as-you-throw MSW pricing program: assuming high medium and low source reduction scenarios

c.4 Household budget impacts

As a general rule, situations with lower municipal HH MSW collection revenue were associated with higher average HH budgets. At an MSW collection price of $0/kg, household budgets increase by the entirety of the avoided $343 HHMSW collection fee under the current flat fee regime. As PAYT price goes up, HH budgets decline to a negative value and do not recover. The baseline results of the CBA revealed that average HH budgets increased at low prices under all scenarios (Figure 4.6). In the higher the source reduction (SR) behavior scenarios, the price at which the change in household budget reaches a break-even point ($0) was greater. This is because improved SR behavior renders household budgets less sensitive to changes in unit price, as less material is being billed for disposal. In the low SR scenario, residents absorb nearly all of the MSW price increase as a decrease in household budget. The SR effects of higher MSW prices slow the decline of household budgets under mid and high source reduction. Under the high SR scenario, high MSW prices induce such a large reduction in MSW generation that household budgets begin to increase back toward the break-even point.

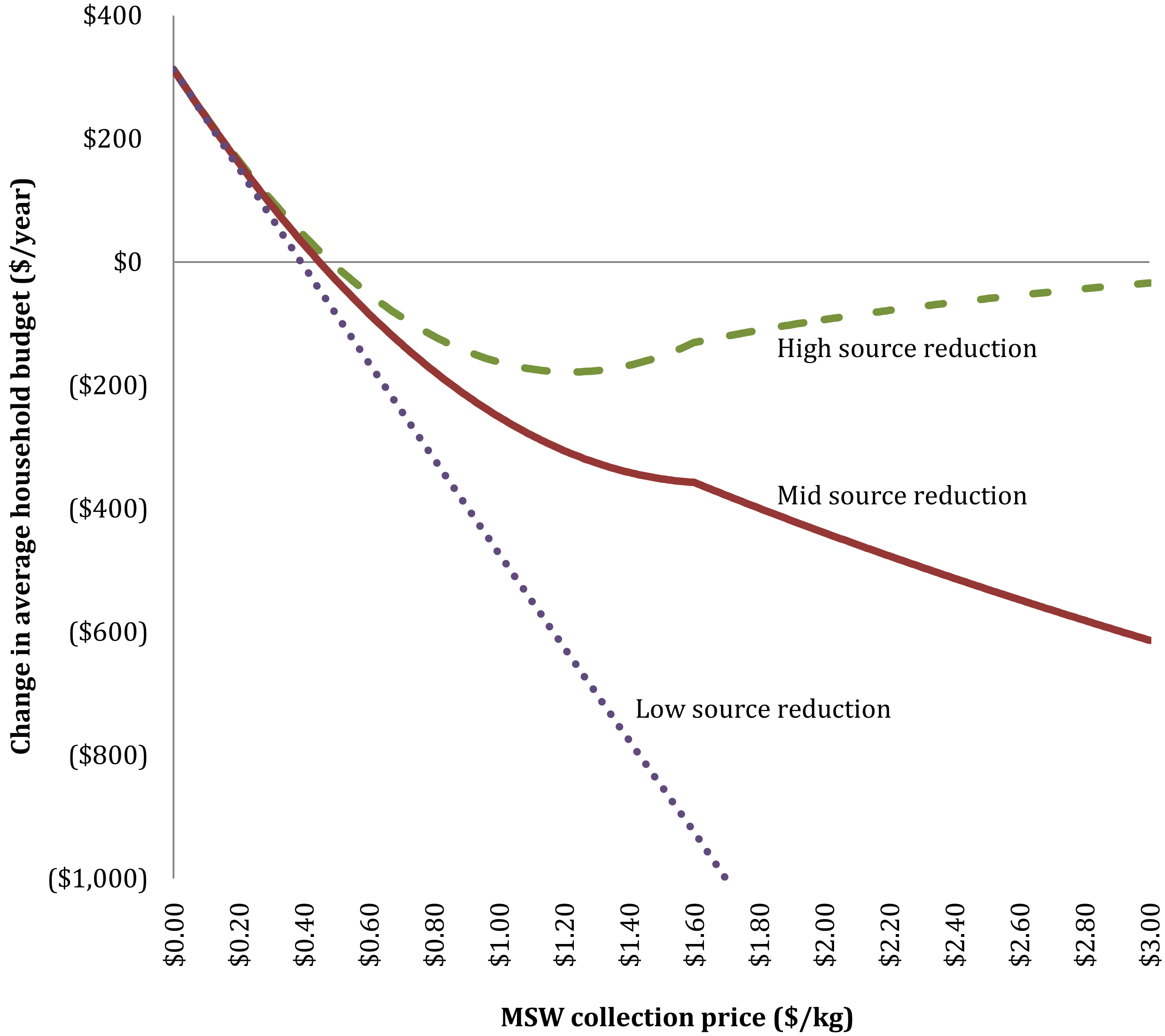


Figure 4.6: Change in average household budget ($/year) with PAYT under different scenarios: high, low, and mid source reduction; private sector organic collection; annual base charge of $0

c.5 PAYT project first-year break even capital & administrative costs

Eight out of the twelve CBA scenarios had optimum MSW prices, at which the change in average HH budget and HHMSW collection budget were both positive (Table 4.7). At the optimums, HHMSW collection revenues were between $24,000,000 and $29,500,000; avoided trucking costs ranged from $310,000 to $1,350,000; and avoided tipping fees spanned $650,000 to $2,810,000. The lower bound of the first year municipal budget impact was $184,000 at the mid source reduction scenario with municipal organic collection, no base charge, and a price of $0.35/kg.

The municipal budget impact values in Table 4.7 do not include capital and administrative costs. As such, they are break-even values where the municipality would receive a first-year net benefit after capital and administrative costs. The upper bound was $3,800,000 under the scenario of high source reduction, private organic collection, no base charge, and a price of $0.54/kg. The lower bound was $780,000 under the scenario of high source reduction, municipal organic collection, no base charge, and a price of $0.35/kg. Of the $3,020,000 difference between the upper and lower bound, 7% was due to HHMSW collection revenue, 63% was due to avoided tipping fees, and the remaining 30% was from avoided trucking costs. This suggests that landfill tipping fees avoided are the major driver of the municipal case for implementing PAYT for household MSW.

Table 4.7: Optimum unit prices for MSW under all scenarios and associated municipal and household impacts

Household MSW source reduction estimate	HH organic material collection provider	Base charge ($/year)	Optimal MSW price ($/kg)	Municipal revenue from HH MSW collection ($/year)	+ Municipal landfill tipping fees avoided ($/year)	+ Municipal trucking costs avoided ($/year)	= Net municipal revenues + avoided costs ($/year)	Municipal break even value for capital & admin. costs ($/year)	Household benefit of program ($/year)
High	Private sector	0	0.54	29,200,000	2,810,000	1,350,000	33,300,000	3,800,000	4.30
		15	0.48	28,000,000	2,700,000	1,300,000	32,000,000	2,500,000	2.40
	Municipal	0	0.35	29,000,000	920,000	440,000	30,300,000	780,000	6.70
		15	No optimum	n/a	n/a	n/a	n/a	n/a	n/a
Mid	Private sector	0	0.5	29,500,000	2,500,000	1,200,000	33,200,000	3,630,000	0.70
		15	0.44	27,800,000	2,400,000	1,200,000	31,400,000	1,810,000	5.40
	Municipal	0	0.34	29,500,000	650,000	310,000	30,500,000	930,000	0.50
		15	No optimum	n/a	n/a	n/a	n/a	n/a	n/a
Low	Private sector	0	0.43	29,500,000	1,800,000	890,000	32,300,000	2,710,000	0.30
		15	0.39	24,000,000	1,800,000	880,000	26,700,000	1,270,000	1.90
	Municipal	0	No optimum	n/a	n/a	n/a	n/a	n/a	n/a
		15	No optimum	n/a	n/a	n/a	n/a	n/a	n/a

c.6 PAYT project net present value under 12 scenarios

As Table 4.8 shows below, the PAYT project NPV over 11 years ranges from $17,900,000 (with low source reduction) to $27,800,000 (with high source reduction) at the reference discount rate of 3.22%. This discount rate is based on the municipal bond yield that would be comparable to what the City of Rochester would have. The rate was based on the yield (as of 4/23/2014) of a 10-year bond from the Monroe County Industrial Development Corporation for a Monroe Community College capital project (MunicipalBonds.com 2014). For a very conservative, high-end estimate of project NPV, the discount rate for the City of Rochester, the rate of 3.22% was tripled to 9.66%, to reflect the event of a sudden decrease in the City of Rochester credit rating or unforeseen increase in municipal bond yields due to a higher interest rate. Even with a conservative discount rate, the project NPV ranges from $12,100,000 (with low source reduction) to $18,100,000 (with high source reduction).

Table 4.8: Financial benefits of implementing a weight-based pay-as-you-throw MSW pricing program in the city of Rochester, NY under three source reduction behavior scenarios

Household MSW source reduction estimate	HHOM collection provider	Base charge ($/year)	Optimal MSW price ($/kg)	Municipal MSW collection revenue ($/year)	Net municipal revenues + avoided costs ($/year)	Capital + admin. costs [Midpoint estimate] ($/year)	Municipality: Total benefit (11 years; no discounting; current dollar)	Municipality: NPV of PAYT (3.22%; 11 years; current dollar)	Municipality: NPV of PAYT (9.66%; 11 years; current dollar)	Household: Total benefit (11 years; no discounting; current dollar)
High	Private sector	0	0.54	29,200,000	3,800,000	2,920,000	$34,600,000	$27,800,000	$18,100,000	$47
Mid	Private sector	0	0.50	29,500,000	3,630,000	2,920,000	$32,800,000	$26,300,000	$18,100,000	$7
Low	Private sector	0	0.43	29,500,000	2,710,000	2,920,000	$22,700,000	$17,900,000	$12,100,000	$4

c.7 Project cash flows

High MSW source reduction scenario

Cash flows were positive through all years of the project, except for year 0 (i.e. immediate time of implementation) where capital expenses were paid up front with money received from the municipal bond. This is the same for project cash flows under all three source reduction scenarios. Under high source reduction, discounted cash flows exceed $2,100,000 for years 1-11.

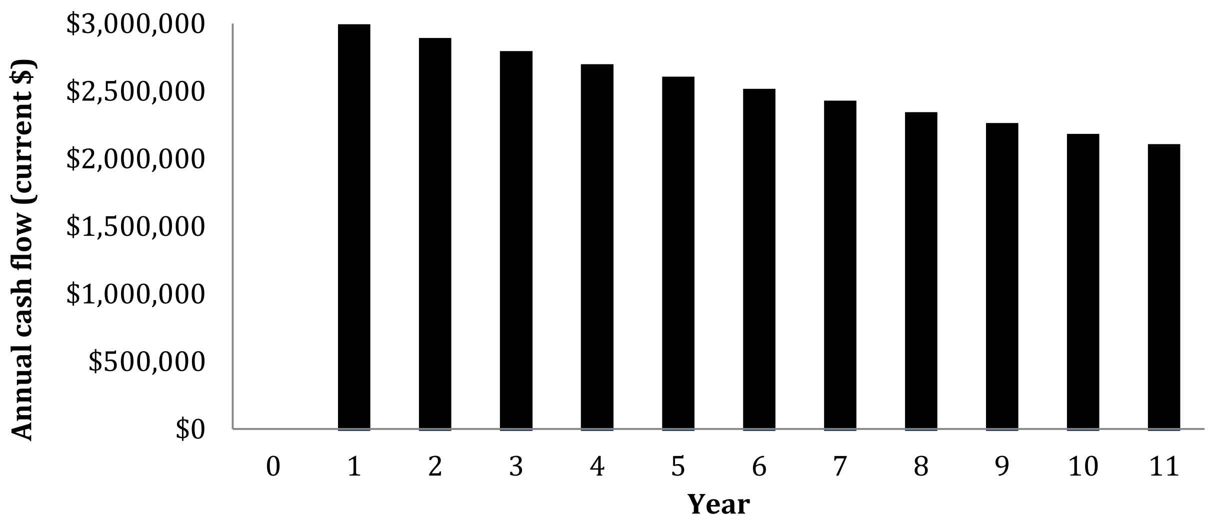


Figure 4.7: Predicted cash flows of pay-as-you-throw MSW pricing program in Rochester, NY: 11 year project at 3.22% discount rate, MSW price of $0.54/kg with no annual base charge, assuming high source reduction and midpoint project cost

Mid MSW source reduction scenario
In the most likely scenario, mid source reduction, discounted cash flows exceed $2,000,000 for years 1-11.

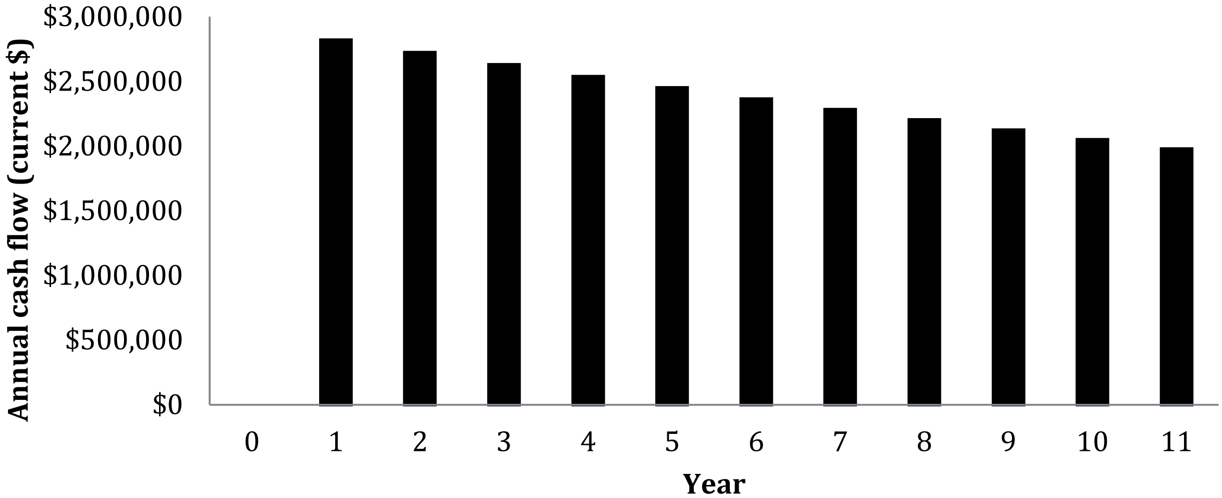


Figure 4.8: Predicted cash flows of pay-as-you-throw MSW pricing program in Rochester, NY: 11 year project at 3.22% discount rate, MSW price of $0.50/kg with no annual base charge, assuming mid source reduction and midpoint project cost

Low MSW source reduction scenario
In the low source reduction scenario likely scenario, discounted cash flows exceed $1,300,000 for years 1-11.

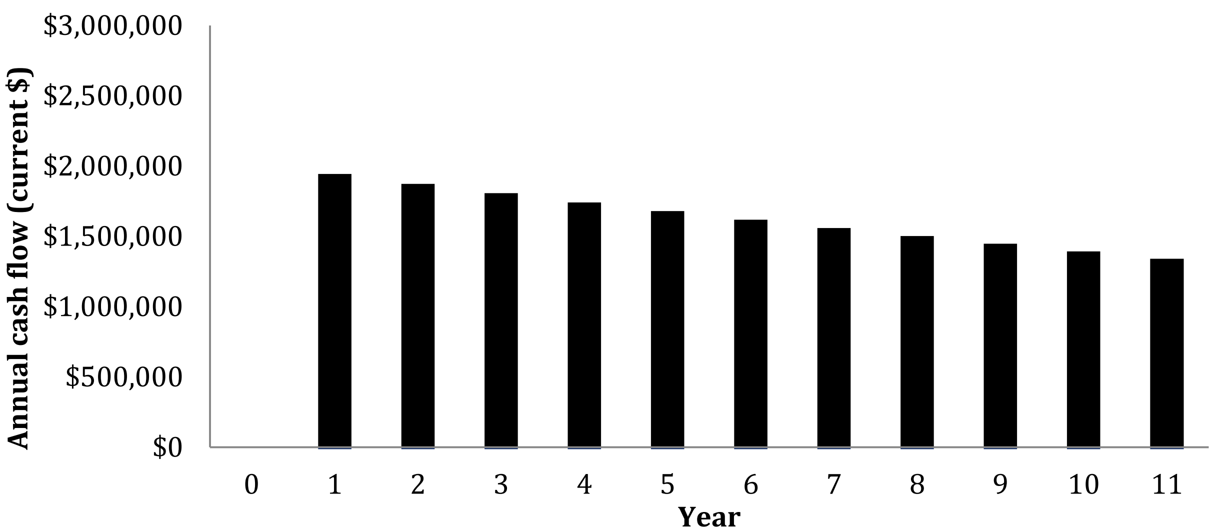


Figure 4.9: Predicted cash flows of pay-as-you-throw MSW pricing program in Rochester, NY: 11 year project at 3.22% discount rate, MSW price of $0.43/kg with no annual base charge, assuming low source reduction and midpoint project cost

d. Key findings and considerations for implementation

A weight-based PAYT project in the city of Rochester, NY has a net present value of between $12,100,000 and $18,100,000 conservatively. The CBA showed that the City of Rochester can maintain a positive project budget at all times by covering capital and administrative the costs of the PAYT project at a competitive interest rate. The project's annual positive net cash flows exceed $1,300,000 with the most conservative MSW source reduction scenario, or $2,100,000 with an optimistic source reduction scenario. Thus, with the current fiscal year City of Rochester budget for solid waste collection is $17,300,000, a PAYT project would save between 7.5% and 8.2% annually (City of Rochester, NY 2013a). This accounts for between Much of the value in the program is derived from avoided costs of landfill tipping fees and trucking operations, while additional revenues are brought in from charging for MSW by the kg. Uncertainty in the pay as you throw fee program cost-benefit analysis could be reduced by determining the true capital and administrative costs of unit pricing in Rochester, NY by pricing out capital equipment and making a budget for the administrative tasks.

Environmentally, the project is beneficial due to the reduction of MSW going to the landfill. At the recommended PAYT prices, the CBA model shows that MSW generation is reduced between 1-22% (Table 4.9). Source reduction of MSW eliminates the need for additional production of goods, thus offsetting environmental impacts associated with disposing in the current management pathways. Household organic materials processing enabled by the PAYT project can produce biofuels and compost. These also have the potential to decrease greenhouse gas emissions by offsetting energy and material uses in the regional economy

Table 4.9: Summary of recommended weight-based PAYT prices under three levels of household MSW source reduction behavior

Source reduction	MSW price ($/kg)	Total MSW generation (MT)	% MSW reduction, PAYT pricing relative to flat fee pricing
high	$0.54	75,000	22%
mid	$0.50	82,000	15%
low	$0.43	96,000	1%

From a household perspective, PAYT pricing presents potential savings on household solid waste collection bills. This CBA has confirmed that separating out organic materials will help residents achieve the lowest possible bill under PAYT pricing. On average, households will save $4-

5 per year from participation, with a range of values around the mean. Theoretically, residents will participate if the implicit cost of their time spent on source separation is lower than the monetary and other benefits (e.g. utility; feeling of doing good) of source separation. If participation becomes a problem for the municipality due to imbalanced opportunity costs, the MSW price should be lowered until participation rises again. Considering the $2-3 million dollar annual (positive) municipal budget impact of the PAYT project, it would likely absorb this adjustment.

From an equity standpoint, it is important that the monetary benefits of a PAYT program accrue to low-income residents without creating an undue burden. Generally, the wage-based monetary value of time is less for residents with lower incomes, so the incentive to source separate materials to save on the MSW collection bill is relatively high. Thus, this program is progressive in that the incentive structure encourages participation from low-income groups. Under a PAYT program, monthly billing cycles allow savings to be achieved and realized quickly. Immediate payback on the returns of organic material management defrays the erosion of benefits to low-income residents resulting from their high implicit discount rates (Hausman 1979). Municipalities such as Dubuque, Iowa have gone a step further by offering a 50% discount on the monthly bill to particular demographics. Low income families of five or more (who naturally produce more MSW), low income elderly, and households meeting Section 8 federal assistance guidelines all receive the benefit. Dubuque also makes exceptions for "hardship cases" approved by the city manager (Linderhof et al. 2001).

Most City of Rochester residents are already in the habit of source separating glass, metal, paper, and plastic items from their MSW for curbside collection. This fact points to a low barrier to adding organic collection. Since residents are already participating in source separation and collection for other materials, they likely have the prerequisite abilities and motivations for organic material management (a very similar process). However, sustainable material management would not be possible without the municipality creating the opportunity to do so (Thogerson 1996). From a municipal perspective, the imperative is to create opportunity to participate. From there, as Vining and Ebreo (1990) highlighted, non-participating residents respond especially well to a positive financial incentive.

Based on the results of the CBA, the optimal price for MSW collection is between $0.43-0.54/kg. This is based on the most likely scenarios with mid-level source reduction and cost estimates. When implementing the program, some flexibility should be allowed for the most appropriate way to apply the price – whether directly through a weight-based program or indirectly through a volume-based one.

It is important to control costs in order to maintain positive municipal budget impacts, especially in cases with lower source reduction behavior. It should be carefully considered what is done with the revenues generated from the pay as you throw policy, and whether or not the surplus funds can be re-invested into the program to cover recurring administrative costs. In addition, a full understanding of tradeoff points in feedstock and PAYT policy parameters is required by the municipal actors implementing the program. This will ensure that they know what areas to focus to remain adaptable to changes in key variables effecting private profit and municipal budget. Given the sensitivity of PAYT project benefits to controlling parameters, thorough reporting by the municipality on household organic material management status (i.e. source reduction behavior, awareness of landfill alternatives) will be required for program evaluation and quality control.

Action Items

In the final analysis, the city of Rochester, NY should accomplish the following steps in order to enable a sustainable HHOM management system:

- Set up public-private partnerships: Enabling private firms to collect and process HHOM has a higher value for the City of Rochester than municipal collection and processing. In practice, firms (e.g. Community Composting, LLC) may specialize in bringing HHOM to processing pathways (e.g. AD run by Synergy Biogas, LLC). Alternatively, processing pathways may choose to pick up the material on their own, complemented by voluntary household HHOM deposits on-site.
- Local AD, SSF, and/or composting firms must be identified: To ensure the long-term success of sustainable HHOM management upon implementing PAYT, private firms must provide the infrastructure to manage regional HHOM.
- Site a windrow composting operation within city limits: This way, the city could eliminate HHOM tipping fees and reduce trucking costs. The city of Rochester, NY has many vacant lots which serve as places for urban composting. This would be ideal for generating compost for regional sale, community donations (e.g. urban agriculture initiatives), or use on public grounds. This composting site would serve as a buffer for excess HHOM (or commercial organic material) that is not picked up by private firms. The site can address various municipal needs for organic material management (e.g. composting fall leaves with food waste).
- Pilot organic recycling: Begin where expected participation and project value is high, namely the Southeast City of Rochester, NY. As more households participate, economies of scale are reached for the municipality and private firms.

- Provide containers for source separated HHOM to those who need them: This can continue until they are provided by private firms, producing a negligible impact on project NPV.
- Bill residents every two weeks by weight of MSW collected: Frequent charges provide households quick feedback on financial impacts of MSW generation.
- Begin with single-stream HHOM collection: Food, yard trimmings, and compostable paper would be collected together as one stream of mixed HHOM. As Chapter 5 and Table 5.10 show, the most profitable pathway for a single-stream system is anaerobic digestion, according to an engineering economic model using data on the city of Rochester, NY.
- Gather, analyze, and publicize data on the pilot: relating to material generation, source separation, resident participation (or delinquency) and resident feedback. Encourage and facilitate community forums to discuss program performance and help apply necessary changes to the pilot. Use evaluations to make a strategic project expansion plan with a timeline for implementation. It is critical to engage a representative cross-section of Rochester's diverse community in regular dialogue. By involving residents in their own MSW service planning and evaluation, project managers ensure project efficiency, continued resident buy-in, and equity among stakeholders.

Chapter 5: Modeling optimal processing pathways for household organic material

a. Introduction

The majority of household organic material (HHOM) in Rochester, NY is processed in landfills with gas capture. Although this management pathway is profitable, there are multiple other pathways for managing HHOM in Rochester, NY – including anaerobic digestion, SSF, and commercial composting. As the literature review in Chapter 2 indicated, these latter three HHOM management pathways can have lower life cycle emissions than landfilling, and make superior contributions to community resilience (e.g. local agriculture promotion, reduced non-renewable resource use). These findings indicate that expanding use of these landfill alternatives for HHOM management will yield superior social and environmental performance compared to landfills with gas capture.

In the private sector, the choice of pathway for HHOM feedstocks is dictated by the potential to maximize profits. The landfill pathway has been institutionalized over its long history of use across the globe, and in Rochester, NY. However, new pathways have emerged that may have even greater potential for profit-maximization. High rates of HHOM landfilling and local economic stagnation have prompted the need to verify that landfills with gas capture remain the profit maximizing management pathway for the city of Rochester, NY.

To help find a solution, an optimization model was formulated to inform private and public stakeholders in the material management system. The model computes the profit-maximizing pathways for HHOM as the difference between total costs (i.e. operations; administration; capital financing) and total revenues (i.e. product sales; tipping fees). Organic material management pathways generate product revenue through biochemical processes that have varying product yields, depending on the chemical parameters of the feedstocks. HHOM is made up of distinct feedstocks (i.e. food, compostable paper, and yard trimmings) with unique chemical parameters and thus the model accounted for this by finding the optimal pathway for each feedstock. The model findings guide rational investment in management infrastructure for food, compostable paper, and yard trimmings by clarifying the potential profitability of available pathways.

b. Methodologies

b.1 Model formulation overview

Based on the difference of total revenues and total costs per kg of HHOM feedstocks, the profit-maximizing pathway was calculated for each. The modeled pathways were based on the processing parameters shown in Table 5.1:

Table 5.1: Industrially relevant processes that served as pathways in the model

Pathway	Process
Landfill with gas capture	High Acres Power Production Plant, Fairport, NY operated by Waste Management; 9.6 MW electric generation system (New Hampshire Public Utility Commission 2013)
Anaerobic digestion	Synergy Biogas, LLC, Covington, NY; 1.4 MW engine-generator set (Rankin 2013a)
SSF	Epiphergy, LLC, Rochester, NY; 10 MT/day capacity (Ebner et al. 2014)
Commercial composting	McEnroe Organic Farm, Windrow Composting, Dutchess County, NY (McEnroe Organic Farm 2013)

Figure 5.1 below is a schematic overview that maps the flow of household organic material through the material management system. Material flows were modeled in Microsoft Excel and the What'sBest! add-in from Lindo Systems was used to formulate constraints and solve for the profit maximizing solution. Each material has different physical parameters (e.g. moisture, sugar content, biomethane potential), and every pathway has unique determinants of profit (e.g. tipping fees, product revenues), and product yields. Additionally, available feedstock quantities and trucking costs are taken into account. The following sections explain the methodology used to derive each of the model components, as well as how they fit together.

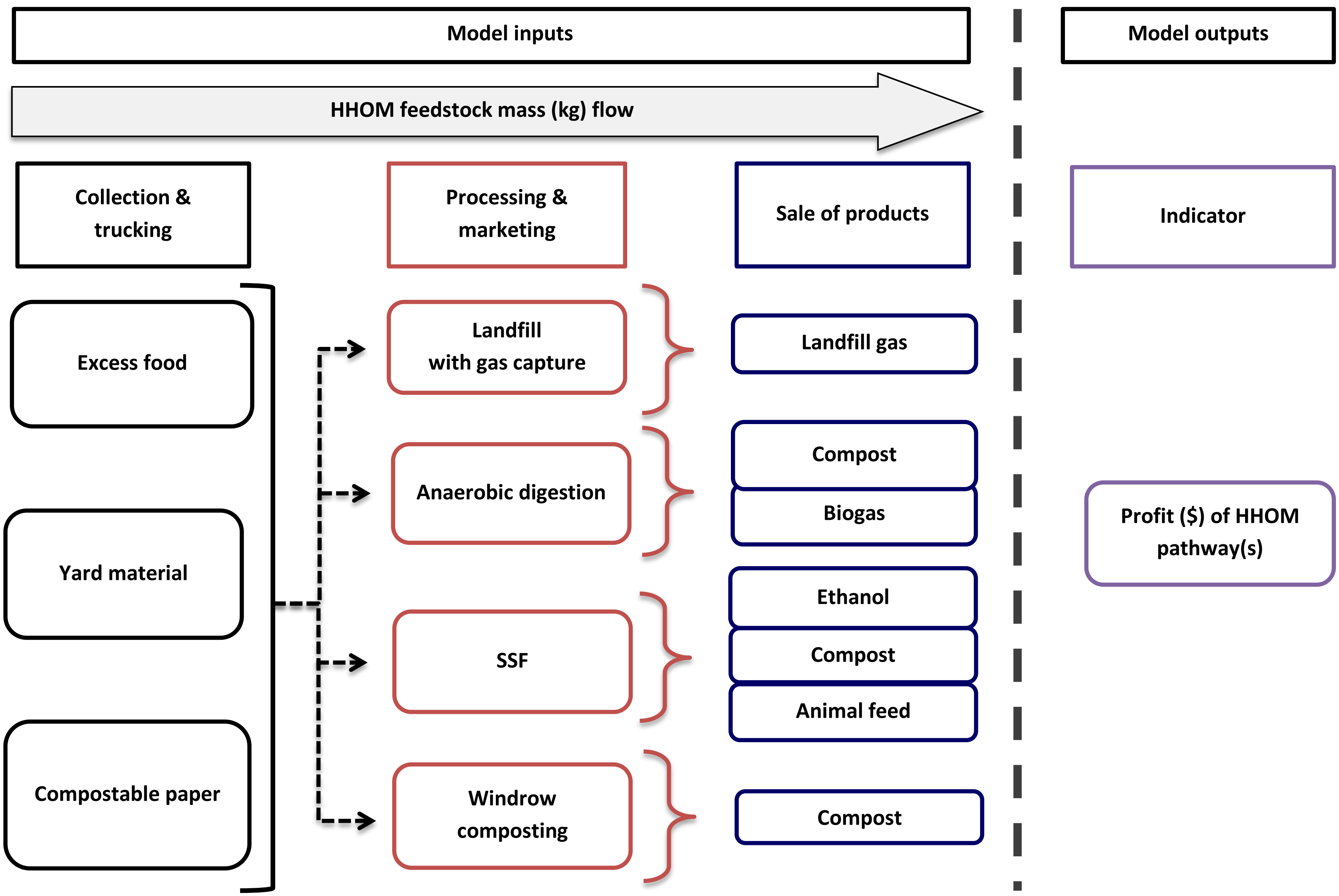


Figure 5.1: Household organic material optimization model overview diagram

b.2 Key parameters

The nomenclatures for algebraic terms that comprise the objective function are named in Table 5.2. The subscripts indicate revenues and costs that are related to a certain HHOM management pathway or product.

Table 5.2: Nomenclature of profit-maximizing organic material management model

Parameter (subscript)	Description
X	HHOM management pathway
P	Product type (i.e. compost, biogas, landfill gas, ethanol, animal feed)
TF	Tipping fee ($/kg)
f	Food
y	Yard matter
cp	Compostable paper
Parameter (superscript)	**Description**
R	Total material management revenue ($/kg wet HHOM)
C	Total material management cost ($/kg wet HHOM)
M	Revenue penalty factor due to product marketing
O	Operating and processing costs ($/kg wet HHOM)
F	Capital financing costs ($/kg wet HHOM)
τ	Trucking cost ($/kg wet HHOM)
Q	Quantity of feedstock (kg wet HHOM)

Generally, the objective function is total revenue minus total cost for each of the four pathways on a per kg basis. It is described by the following equation:

$$Profit\ Max = Q_{f,y,cp} \times (R_{LF} - C_{LF}) + Q_{f,y,cp} \times (R_{AD} - C_{AD}) + Q_{f,y,cp} \times (R_{SSF} - C_{SSF}) + Q_{f,y,cp} \times (R_{COM} - C_{COM})$$

The objective function is the quantity of food, yard, and compostable paper going through each management pathway, multiplied by the profitability of the management pathway relative to each feedstock. For example, food going through the landfill with gas capture has different revenues and costs than food going through anaerobic digestion.

While the revenue and cost parameters influence profitability ($ profit/kg wet HHOM), overall profits ($) depend on the amount of feedstock going through the management pathways. At the front end of the model, the mass of feedstocks generated annually in the city of Rochester, NY was calculated. They were assumed to be source separated into three streams by households. This assumption is in accordance with: 1) the very high material separation rates observed when households are charged by weight of MSW generated (Skumatz and Freeman 2006); 2) successful implementation of a pay-as-you-throw MSW pricing program (see Chapters 3 and 4).

The latest municipal solid waste characterization studies from the Department of Environmental Conservation (NYSDEC 2008) provided the basic assumptions for calculating the amount of available household organic material. The annual mass (kg) of food, compostable paper, and yard trimmings in the household MSW stream were determined by first multiplying the annual per capita MSW generation by the city population to get total MSW generated per year. This was then multiplied by the proportion of residential MSW (0.52 kg residential MSW/kg total MSW) (NYSDEC 2008) in total MSW to get total annual MSW generated (see equation below).

$$Annual\ household\ generation\ (kg)\ of\ food, compostable\ paper, and\ yard\ trimmings$$

$$= \frac{850\ kg\ total}{resident\ \cdot\ year} \times 210{,}565\ residents \times \frac{0.54\ kg\ residential\ MSW}{kg\ total\ MSW}$$

$$= \frac{93{,}073{,}000\ kg\ residential\ MSW}{year}$$

The annual generation of each feedstock was determined by multiplying the annual HHOM by the given mass percent of the feedstock in MSW for urban, residential areas. Table 5.3 shows the quantities of each material available in the city of Rochester, NY.

Table 5.3: City of Rochester, NY HHOM generation quantities (baseline model inputs)

Feedstock	Wet mass (MT/year)	Percent of HHOM generation
Total	26,247	100%
Yard trimmings	3,909	15%
Excess food	16,009	61%
Compostable paper	6,329	24%

b.3 Constraints

The model constraints ensure use of feedstocks as well as mass conservation. Three constraints ensure that the mass of food, yard matter, and compostable paper available in the city of Rochester, NY are equivalent to the food, yard matter, and compostable paper to going through all four pathways. An additional constraint ensures conservation of mass from raw feedstock to finished products by requiring that the mass of all products (including waste) made from the pathways are equivalent to the available mass of HHOM feedstocks.

b.4 Pathway revenues

The revenue component (R_X) of the objective function is shown by the following equation:

$$R_X = R_{TF} + \sum [R_P \times M_P]$$

Pathway revenues are a combination of the tipping fee for disposing of the material and the price at which manufactured products from the pathway are sold on the market. The revenue (R_P) is scaled by the marketing factor (M) accounting for revenue eroded by overhead from product promotion and sales activity. It is important to note that R_P can encompass multiple products (see "notation subscript variables). The same products can be produced by multiple pathways (e.g. compost is created through SSF, anaerobic digestion, and composting). However, the operating costs assigned to creating those products belong to the pathway producing them. For example, compost produced from SSF has an operating cost (O_{SSF}) that is different from compost produced from AD (O_{AD}) or composting (O_{COM}).

Baseline product revenues

The ethanol product is distiller's beer from a local SSF facility as described by Ebner et al. 2014. Distiller's beer has up to 18% ethanol content or as low as 12%. The highest price that large-scale ethanol refineries are willing to pay for distiller's beer is $0.40-2.75/gal pure ethanol (Ebner 2012; Fennie 2014). Considering the volatility of the ethanol market, the model baseline used the mid-point of the ethanol price range, which is $1.58. Sensitivity of optimal SSF pathway profits were examined for differing ethanol prices when applicable (see section e.2; Figures 5.17-5.19 in this chapter).

Compost from the local SSF process price varies from $0.11/kg to $0.55/kg for compost depending on quality (Ebner et al. 2014). The model baseline input used the low-end value ($0.11/kg compost). This was done for two reasons: 1) $0.11/kg price was quoted directly from the local firm running the SSF process (Ebner 2012); 2) data from the local SSF process on the quality of compost produced was unavailable. The market price for dried distiller's grain solids of animal feed quality is $250 per metric ton, or $0.25/kg feed (Alibaba.com 2014). This feed was determined to be equivalent quality for a representative local SSF pathway (Fennie 2014).

For the anaerobic digestion pathway, two products are produced – compost and biogas. The model can be run under two revenue-producing scenarios: 1) biogas cleanup for vehicular applications and, 2) on-site generation of electricity to sell to the grid. This was done in order to compare profitability between two popular configurations of AD systems. The model baseline scenario was on-site generation with grid feed-in. This scenario is currently being carried out at the industrially relevant AD site used in the optimization model. In the grid feed-in scenario, biogas revenue is calculated by multiplying biogas energy content per unit volume by biogas density (Ludington 2014), as well as the feed-in price of electricity in New York State (NYISO 2014) and a kWh to BTU conversion factor:

$$\frac{578\,BTU}{ft^3} \times \frac{29.013\,ft^3}{kg} \times \frac{\$0.06}{kWh} \times \frac{kWh}{BTU} = \frac{\$0.295}{kg}$$

In the cleanup scenario, net biogas revenue is calculated by subtracting biogas cleanup cost from the clean biogas revenue. To get clean biogas revenue ($/kg biogas), the average price of natural gas per therm (from January 2013 to January 2013) (Bureau of Labor Statistics 2014a) is multiplied by a conversion factor of therms to British Thermal Units (BTU), as well as the lower heating value and density of the biogas (Ludington 2014). A low-end of 60% methane content is assumed for the biogas (Voell 2009). Then the cleanup cost ($/kg biogas) is calculated by multiplying the cleanup cost in dollars per gallon of gasoline equivalent (GGE) (Michels, 2012) by biogas energy content in BTU per GGE, the lower heating value (LHV), and the density of biogas (Ludington 2014).

$$\frac{\$1.18169}{therm} \times \frac{therm}{99976.129\ BTU} \times \frac{578\ BTU}{ft^3} \times \frac{29.013\ ft^3}{kg} - \frac{\$70}{GGE} \times \frac{GGE}{114000\ BTU} \frac{578\ BTU}{ft^3} \times \frac{29.013\ ft^3}{kg} = \frac{\$0.0952}{kg}$$

For both the grid feed-in (baseline) and cleanup scenarios, compost was a co-product with biogas. Compost revenue from AD utilized the \$0.33/kg midpoint value of the range of compost revenues (\$0.11/kg - \$0.55/kg) (Ebner et al. 2014) for the AD pathway. The midpoint was chosen to help account for compost price volatility.

For the composting pathway, the model baseline utilized the \$0.33/kg midpoint value of the range of compost revenues (\$0.11/kg - \$0.55/kg) (Ebner et al. 2014) for the compost pathway to account for compost market volatility.

To quantify the economic benefits of the landfill gas system, annual net income of the landfill gas system was used in place of gross revenue. At the industrially relevant landfill used in the model, landfill gas is used on site and isn't sold externally as an electricity or fuel product (Waste Management 2013a). Landfill gas has a reported net income of \$1.00/mmBTU at sites operated by Waste Management such as the local High Acres landfill (Messics 2001). Net income was multiplied by yielded biogas (discussed later) to get total landfill gas income. Cumulative inflation from 2001 to 2014 is assumed to be equivalent for both costs and revenues associated with landfill gas production, thus no adjustment was made.

Baseline tipping fees

For the landfill with gas capture, the quoted price from Waste Management, Inc. (the City of Rochester, NY municipal solid waste hauler) is \$60/short ton, or \$0.66/kg (Waste Management 2013c) after unit conversion (below).

$$\frac{\$60}{short\ ton} \times \frac{1.1\ short\ ton}{1\ tonne} \times \frac{1\ tonne}{1000\ kg} = \frac{\$0.066}{kg}$$

A local SSF pathway has quoted their tipping fee as \$20/MT, or \$0.02/kg organic input (Ebner 2012). For windrow composting, the quoted price is \$35/short ton (McEnroe Farms 2013). This was converted to metric tons to arrive at \$0.039/kg organic input (below).

$$\frac{\$35}{short\ ton\ organic\ input} \times \frac{1.1\ short\ ton\ organic\ input}{1\ tonne\ organic\ input} \times \frac{1\ tonne\ organic\ input}{1000\ kg\ organic\ input}$$
$$= \frac{\$0.039}{kg\ organic\ input}$$

The tipping fee charged by the Synergy Biogas anaerobic digester was derived from the reported average tipping fee of \$0.05/gal (range \$0.04-0.10/gal) (Rankin 2013b). First, the mass (kg) of a gallon of organic input was calculated from the density of the shredded organic fraction of municipal solid waste. The reported density of 1,060 kg/m^3 (Forster-Carneiro et al. 2008) was multiplied by the unit conversion factor to obtain 4.012 kg/gal.

$$\frac{1\ kg}{m^3} = \frac{0.003785\ kg}{gal}$$
$$\frac{0.003785\ kg}{gal} \times \frac{1060\ kg}{m^3} = 4.012 kg/gal$$

As shown below, the tipping fee per kg was found by dividing a gallon of organic input by the mass of a gallon of the shredded organic fraction of municipal solid waste (Forster-Carneiro et al. 2008). The range of tipping fees is 0.00997 to 0.0249 dollars per kg.

$$\frac{\$0.05}{gal\ organic\ input} \div \frac{4.012 kg}{gal\ organic\ input} = \frac{\$0.0125}{kg\ organic\ input}$$

b.5 Pathway costs

The options for material management systems are normally constrained by the characteristics of the organic material and process parameters such as feedstock cost. These can quickly inform on the merits and potential challenges of a production process (Klein-Marcuschamer and Blanch 2013; Barton et al. 2008). Feedstock cost in this case is zero, since municipal "waste" organic materials (i.e. municipal food, yard trimmings, and compostable paper) are being used. As such, the cost parameter for each management pathway consisted of: 1) operation and administration costs due to HHOM processing and conversion to value-added products; 2) capital financing costs; and 3) HHOM trucking. The following equation demonstrates this relationship:

$$C_X = \sum [O_X + F_X + \tau_X]$$

Operating costs

Operating costs in this model included all direct labor, mechanical operations, and maintenance costs. A local SSF pathway has quoted the cost to process organic input at $30/MT, or $0.03/kg organic input (Ebner 2012). Total operation cost is the product of kg inputs and the cost per kg input. In the case of supplementary process water for compost and animal feed co-products, the cost in $/year is added on. Windrow composting variable cost is quoted at $0.0118/kg (Steuteville 1995), and compensating for 56% cumulative USD inflation from 1995 to 2014 (Bureau of Labor Statistics 2014b), that becomes $0.0184/kg. The cost of operating the landfill (excluding gas capture) was quoted by Waste Management as 50% of the quoted tipping fee, which equates to $0.33/kg (Waste Management 2013c).

The cost of running the anaerobic digestion pathway per kg of material going through is calculated using data from Synergy Biogas LLC (Rankin 2013b). The first step is to convert the material throughput data from volume to mass by dividing by the material density. The Synergy digester is designed for a loading rate of 100,000 gallons per day – 55,000 gallons are for manure and the remaining 45,000 gallons of which could accommodate household organic material. The hydraulic retention time (HRT) (i.e. the duration that the organic mass is in the digester before biogas production is complete) is 22 days. As such, 45,000 gallons divided by 22 days is the household organic material loading rate in kg per day. This is multiplied by the density in kg per gallon of the material (below). Household organic fraction of MSW has a density of 1060 kg/m^3 (Forster-Carneiro et al. 2008).

$$\frac{1\ m^3}{264.2\ gal} \times \frac{1060 kg}{m^3} = 4.012\ kg/gal$$

$$\frac{4.012 kg}{gal} \times \frac{45{,}000\ gal}{22\ days\ HRT} = 8{,}206\ kg/day$$

Using an 83% capacity factor (i.e. percentage of time operational and producing biogas) from Synergy (maximum monthly average for year 2012) (Rankin 2013a), the daily mass throughput is multiplied by operational days to get annual throughput.

$$365\ days\ \times 0.83 \times 8{,}206 \frac{kg}{day} = 2{,}486{,}000 \frac{kg}{year}$$

Annual maintenance costs are divided by annual throughput to get cost per kg of throughput.

$$\frac{\$103{,}000}{year} \div 2{,}486{,}000 \frac{kg}{year} = \frac{\$0.041}{kg}$$

Revenue penalty factor due to product marketing and sales

The sustainability benefits of different treatment methods depend significantly on markets for associated products (energy and compost) (European Commission 2008). This is taken into account using a revenue scaling factor (i.e. marketing cost) describing the transaction costs of participating in the market for a specific product. The magnitude of the factor is based on a range of values from the literature on percent of sales spend on marketing and selling a product. The amount of total sales revenue spent on marketing and sales activities ranges from 7-20% (Beesley 2013). The revenue penalty factor is calculated by subtracting the marketing budget as a percent of sales (e.g. 20%) from the total revenue (e.g. 100%) to get the scaled revenue (e.g. 80%).

Marketing and sales costs are mainly operating costs (e.g. market research) but can also include semi-variable costs (e.g. transportation to meet prospective clients) and capital costs (e.g. re-painting a vehicle with a company advertisement). Small companies (such as those running the relevant AD, SSF, and composting processes used in the model) need to allocate more time and effort to sell their new products (Beesley 2013; McKee 2009). Examples are brand development; researching customer preferences and requirements; outreach to raise awareness of new products, identifying customers; developing contracts; etc. These short-term costs are long-term investments in product deal flow to help reduce the risk of new product failure (Ogawa and Piller 2006). Thus, company size and product novelty were the two factors that influenced the choice of revenue penalty factor for each product. Sensitivity analysis was performed on revenue penalty factor (see Section e.3; Figures 5.27-5.30). Table 5.4 shows the revenue penalty factor due to product marketing for each of the five possible products from HHOM pathways in the model.

Table 5.4: Baseline revenue penalty factor due to product marketing

Product	Factor
Landfill gas	1
Ethanol (distiller's beer)	0.8
Animal feed	0.93
Compost	0.93
Biogas feed-in electricity	0.8
Biogas clean-up	0.8

Ethanol distiller's beer from SSF was considered to be a new product from a small company. As such, it had the upper-bound revenue penalty applied (0.8) to account for a larger marketing and sales budget. However, the animal feed and compost products of SSF are equivalent to widely traded animal feed and compost commodities. Even though they come from a small company, the existing market is well-defined. Thus, the lower-bound revenue penalty was applied (0.93) for these two products. Similarly, the biogas from AD was considered to be a new product from a small company and had the upper-bound revenue penalty applied in the baseline case. The compost product was considered well-established and thus had the lower-bound penalty applied. Landfill gas was considered to have no revenue erosion due to product marketing. Landfills are the status quo management pathway and currently operate with on-site landfill gas systems in place.

Trucking costs

The daily costs of running a single truck were calculated using a Freight Metrics tool (FreightMetrics.com 2014). The default assumptions on FreightMetrics were used (see FreightMetrics 2014) except for what is listed in Table 5.5:

Table 5.5: Profit maximization model custom trucking cost assumptions for FreightMetrics tool

Parameter	Custom value
On-highway diesel fuel price	$4.16/gal (EIA 2014)
Truck type	24 short-ton single tipper truck (FreightMetrics 2014)
Miles traveled per day for MSW collection	70 (INFORM 2014)
Capital interest rate	8%
Depreciation rate	5%

Using the FreightMetrics tool, calculated cost per truck is $691.83/day. This was divided by truck capacity (21,700 kg or 24 short-tons) to get the unit trucking cost of $0.032/kg. This cost is independent of the number of collection days and trucks on the road. Miles traveled per day was assumed to be the average distance traveled by MSW collection trucks in the US (i.e. 70 miles).

Capital costs

The Synergy Biogas anaerobic digester cost $7,500,000 to build and install (Labatut and Gooch 2012). It was assumed that the costs are financed at 8% interest (compounded monthly) and amortized over 10 years with monthly payments. As such, total payments are $1,091,948.35 each year. Synergy Biogas processed about 35,770,000 kg of material in the year 2012 (Rankin 2013a). Dividing that amount (kg) into the total annual payments ($) puts capital cost per kg processed at $0.031/kg.

Windrow composting capital cost is quoted at $0.0102/kg (Steuteville 1995), and compensating for 56% cumulative USD inflation from 1995 to 2014 (Bureau of Labor Statistics 2014b), that becomes $0.0159/kg. The capital costs of a local SSF facility were quoted as $66/MT processed material, or $0.00066/kg processed material (Fennie 2014). For landfill with gas capture, no new infrastructure needs to be put in place. Existing capital costs are subsumed in the operating cost estimate (Waste Management 2013c), thus capital financing cost is assumed $0/kg.

b.6 Product yields from organic material management pathways

Input parameters

For the excess food and compostable paper feedstocks, empirical data on C:N ratio, total solids (TS), and biomethane potential (BMP) was gathered. Empirical data for co-digestion with manure from the Synergy Biogas digester in Covington, NY was used. This is because it is assumed that the digester serving the city of Rochester, NY would be co-digested with manure, which generally improves biogas yields compared to separate digestion of the feedstocks (EPA 2014).

Where empirical data was not feasible to obtain, feedstock chemical parameters were gathered from available literature. However, empirical data was collected for moisture content, carbon to nitrogen ratio (C:N), and biomethane potential (BMP). Moisture content was found using a Standard Methods 2540 A-G (APHA 1997) percent total solids test, and was verified by an external contractor using Standard Method 2540B. Carbon to nitrogen ratios were observed by an external contractor using the Carbon and Nitrogen Elemental Analysis by Modified ASTM D5291-10. Relative to anaerobic digestion, BMP (mL methane per g volatile solids) was tested by the author and colleagues using gas chromatography (GC) in the Energy Development Lab of the Golisano Institute for Sustainability at RIT (Figure 5.2).

Figure 5.2: Collecting data on the biomethane potential of household organic material using gas chromatography

Feedstock BMP was gathered for household excess food and compostable paper (see Appendix F for feedstock composition). The test was performed in line with Owen et al. (1979). Substrates were prepared using a high-power blender to liquefy the HHOM (Figures 5.3 and 5.4). Inoculum was obtained from the effluent of the model digester, processing 30% industrial food waste and 70% dairy manure. At least two duplicate samples of each mix were prepared and tested in order to account for sample variability. The sample inoculum to substrate ratio was ~2, and the organic loading rate (g volatile solids/L) was ~2.3. There was no pH adjustment, and no mineral medium was added. The incubation was at 37 degrees Celsius and the duration of the test was 32 days. The biogas was gathered with a syringe displacement method and manually injected into the GC. Testing was carried out on a Shimadzu GC-2014 Standard Capillary and Packed Gas Chromatograph. Results are shown in section C of this chapter, Table 5.8.

Figure 5.3: Lab setup for HHOM substrate preparation for gas chromatography

Figure 5.4: Compostable paper substrate for gas chromatography

The following input parameters are referred to the process yields section. Each feedstock has unique parameters that affect the product yields of each pathway, as Table 5.6 shows. Laboratory data observed through first-hand testing were used in this work when possible, otherwise data from the literature was used. For the SSF pathway parameters, the literature review indicated that product yields (and thus profits) increase with larger values of the parameters SSF in table 5.x (i.e. sugar contents and total solids). Thus, the lower bound values were used whenever possible in order to produce a conservative estimate of SSF profitability. For the composting pathway, lower bound C:N was used in order to account for the typically lower C:N of freshly trimmed yard materials as opposed to those that have aged (Rynk, 1992).

Table 5.6: Chemical parameters of household organic feedstocks in the model (highlighted yellow cells used in baseline)

Pathway	Parameter		F Sample	F Lit	Reference	Y Lit	Reference	CP Sample	CP Lit	Reference
Anaerobic digestion (AD)	Volatile solids (kg VS /kg wet feedstock)		0.296	0.095	Food; Moody et al. (2011)	0.905	Switchgrass; Labatut et al. (2011)	0.129	n/a	n/a
	Biomethane Potential (mL CH4/ g VS)		358.5	290	Food; Moody et al. (2011)	122.2	Switchgrass; Labatut et al. (2011)	341.8	n/a	n/a
Simultaneous saccharification & fermentation (SSF)	Cellulose (g/kg VS)	Lower bound	n/a	95	Cabbage, raw; Labatut et al. (2011)	488	Switchgrass; Labatut et al. (2011)	n/a	620	Food-soiled paper sludge; Fan et al. (2003)
		Upper bound	n/a	362	Potatoes, raw; Labatut et al. (2011)	n/a	n/a	n/a	n/a	n/a
	Sugar, starch, pectin (g/kg VS)	Lower bound	n/a	446	Cabbage; Labatut et al. (2011)	0	Switchgrass; Labatut et al. (2011)	n/a	25	Food-soiled paper sludge; Fan et al. (2003)
		Upper bound	n/a	991	Cola beverage; Labatut et al. (2011)	n/a	n/a	n/a	n/a	n/a
	Hemicellulose (g/kg VS)	Lower bound	n/a	95	Cabbage; Labatut et al. (2011)	422	Switchgrass; Labatut et al. (2011)	n/a	115	Food-soiled paper sludge; Fan et al. (2003)
		Upper bound	n/a	362	Meat pasta; Labatut et al (2011)	n/a	n/a	n/a	n/a	n/a
Windrow Composting (COM)	Carbon to nitrogen ratio (C:N)	Lower bound	9.98	14	Municipal food waste; Rynk, R. (1992)	10	Grass clippings; Rynk, R. (1992)	18.67	34	Mixed food and paper; Rynk, R. (1992)
		Upper bound		16		200	Sawdust; Rynk, R. (1992)		178	Paper from domestic refuse; Rynk, R. (1992)
SSF & COM	Total solids (kg TS/kg wet feedstock)	Lower bound	0.311	n/a	n/a	0.930	Switchgrass; Labatut et al. (2011)	0.129	0.54	Refuse stream; NYC DSB WPPP (2005)
		Upper bound	n/a	n/a	n/a	n/a	n/a	n/a	0.70	Recycling stream; NYC DSB WPPP (2005)

LF pathway

Since net income per million British Thermal Units (mmBTU) is used for profit in the landfill gas energy process, what is needed is a yield in mmBTU per kg of wet input. To arrive there, a relationship between landfill gas energy production and mass of organic input is established. The annual amount of energy produced by the landfill gas to energy system is calculated by multiplying landfill gas LHV per unit volume (Messics 2001) by the annual volume of landfill gas produced (Waste Management 2013a). This value is then converted to mmBTU per year.

$$\frac{500\ btu}{scf} \times \frac{3{,}956{,}016{,}000\ scf}{year} = \frac{1.978 \times 10^{12} btu}{year} \times \frac{1\ mmbtu}{1{,}000{,}000\ btu} = \frac{1{,}978{,}000\ mmbtu}{year}$$

To get landfill gas energy produced per unit organic mass, annual energy production is divided by the annual organic input of MSW to the landfill. Organic material is what creates landfill gas. Organic inputs in *disposed* MSW that anaerobically decompose to produce gas include paper, food scraps, yard trimmings and wood – which make up 27%, 22%, 2% and 4% of disposed MSW respectively. Thus the sum of the organic inputs is the gas-contributing organic fraction of MSW – that is 55%. Based on 305,932 short tons of MSW that entered High Acres landfill in 2012 (Waste Management 2013a), the organic fraction is equivalent to 169,242 short tons. From there, the value with units of mmBTU per short ton is converted to MJ per kg of wet organic input.

$$\begin{aligned} &\frac{1{,}978{,}000\ mmBTU}{year} \div \frac{169{,}242\ short\ tons\ wet\ organic\ input}{year} \\ &\quad \times \frac{1.1\ short\ tons\ of\ wet\ organic\ input}{1\ tonne\ of\ wet\ organic\ input} \\ &\quad = \frac{12.86\ mmBTU}{tonne\ of\ wet\ organic\ input} \times \frac{1\ tonne\ wet\ organic\ input}{1{,}000\ kg\ of\ wet\ organic\ input} \\ &\quad = \frac{0.013\ mmBTU}{kg\ wet\ organic\ input} \times \frac{1{,}055.06\ MJ}{1\ mmBTU} = \frac{13.71\ MJ}{kg\ wet\ organic\ input} \end{aligned}$$

Note: although landfill gas is produced over a 10 year period (Agency for Toxic Substances and Disease Registry 2001) it is assumed that the current year organic inputs are producing gas, because the High Acres facility has been operating for over 10 years (since 1971).

COM pathway

Compost percent yield indicates the conversion efficiency of the feedstocks to mature compost, unfinished compost, and waste (watery leachate and carbon dioxide). The two main relationships that effect compost yields are C:N ratio and moisture content. If C:N is too high or too low, it will take longer to create finished compost. Both carbon and nitrogen are required for efficient composting – carbon provides an energy source for aerobic bacteria, while nitrogen provides an essential nutrient. Materials that contain very little nitrogen will break down over time, but they will never reach the temperatures needed for hot composting. If the compost mix is too low in nitrogen, it will not heat up and promote healthy bacterial growth. If the nitrogen proportion is too high, the compost may become too hot, killing the compost microorganisms) or go to anaerobic conditions (bringing composting to a near halt) (City of Euless 2013; Richard and Trautmann 2014). Ideal C:N ratio for efficient composting is 35 (Richard and Trautmann 2014). Moisture content plays a role in maintaining a healthy environment for aerobic composting bacteria. If it is too high (greater than 50%) the air pores in the substrate fill with water and promote anaerobic conditions by crowding out oxygen. If it is lower than 50%, the aerobic bacteria will not have enough water for optimal growth and organic material decomposition (Richard and Trautmann 1996).

In practice, there are technological solutions that can remedy imbalances in each parameter to maintain yields for an additional cost. Thus, composting profit can be reduced by feedstock chemical parameters and the amount of pre-processing used to maximize yields. In the absence of reliable cost information on pre-processing, the yield reduction approach was used to account for the costs of suboptimal processing conditions.

The finished compost yield is determined from the average value of percent yield from triangular distributions for the carbon to nitrogen ratio (C:N) and moisture content. Feedstock inputs are multiplied by average yields and then multiplied by an efficiency factor. In all the composting processes in the model, mass loss due to leachate and carbon dioxide emissions is assumed to be 53% from feedstock to finished compost (Tiquia et al. 2012). Therefore, a scaling factor of 0.53 is applied to compost yielded from the average of the triangular distributions for C:N and moisture content. The equation below expresses the yield relationship:

$$
\begin{aligned}
&finished\ compost\ yield\ (kg) \\
&= \Bigg[food\ input\ (kg) \times \left(\frac{\%\ yield\ given\ food\ \%\ moisture + \%\ yield\ given\ food\ C{:}N}{2}\right) \\
&+ yard\ input\ (kg) \times \left(\frac{\%\ yield\ given\ yard\ \%\ moisture + \%\ yield\ given\ yard\ C{:}N}{2}\right) \\
&+ food\ input\ (kg) \\
&\times \left(\frac{\%\ yield\ given\ compostable\ paper\ \%\ moisture + \%\ yield\ given\ compostable\ paper\ C{:}N}{2}\right)\Bigg] \\
&\times \frac{kg\ finished\ compost}{kg\ compost\ input}
\end{aligned}
$$

A triangular distribution was used to capture the effect of decreasing yield away from the optimal input parameter values for C:N and moisture. Below is the general equation for both of the triangular distributions (x_a = lower bound; x_b = upper bound; x_c = modal value). Figures 5.5 and 5.6 show the distributions used in the model for compost yield as it relates to C:N ratio and moisture content.

$$f(x; x_a, x_b, x_c) = \begin{cases} 0 & x < x_a \\ \dfrac{(x - x_a)}{(x_b - x_a)} & x_b \le x \le x_a \\ -\dfrac{(x - x_c)}{(x_c - x_b)} & x_c \le x \le x_b \\ 0 & x > x_c \end{cases}$$

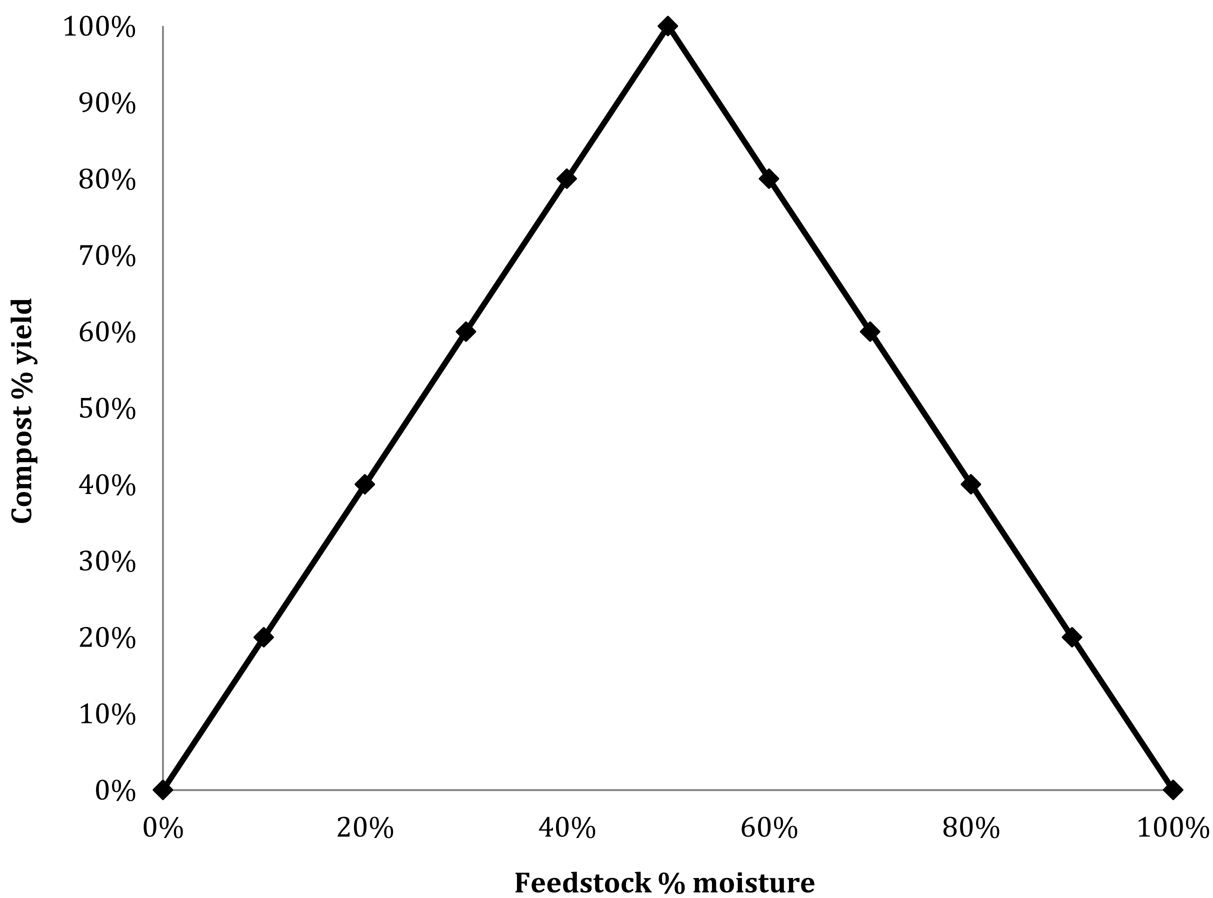


Figure 5.5: triangular distribution characterizing relationship between composting yield and feedstock moisture content

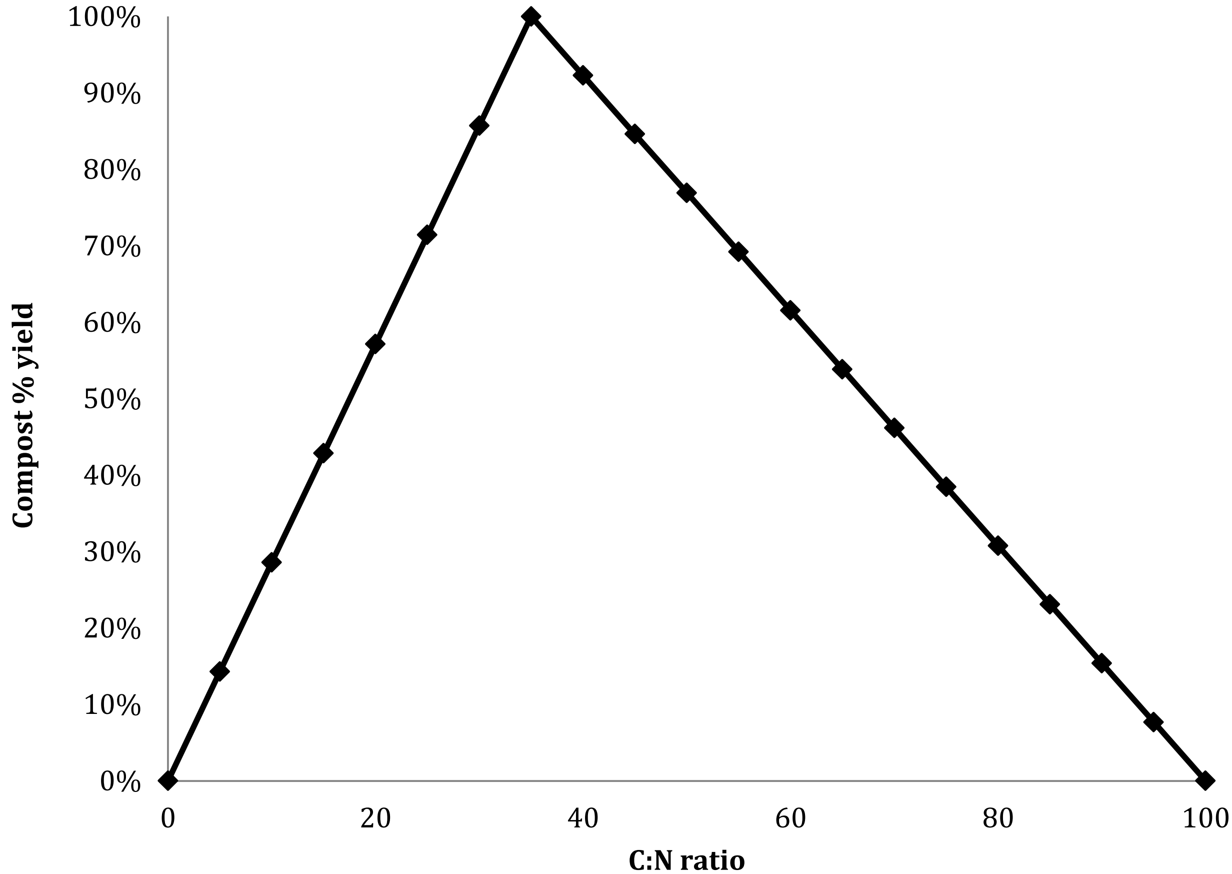


Figure 5.6: triangular distribution characterizing relationship between compost yield and feedstock C:N ratio

At suboptimal conditions, not all of the HHOM is converted to compost, so a waste product is calculated. It accounts for two things: 1) composting emissions (i.e. leachate and carbon dioxide) and, 2) the feedstock remaining in the composting pathway as unfinished compost. This is calculated by subtracting the mass of finished compost from the mass in the compost pathway. The equation below demonstrates this in general form:

$$unfinished\ compost\ and\ waste\ (kg) = \ kg\ wet\ feed\ stock\ in\ compost\ pathway - kg\ compost$$

SSF pathway

The SSF pathway yields five products: 1) ethanol; 2) carbon dioxide; 3) compost; 4) animal feed; and 5) wastewater/added water. Ethanol, compost, and animal feed are sold while the carbon dioxide and wastewater/added water products are not. The yield for pure ethanol was on theoretical conversion efficiency, co-product yields, and feedstock chemical inputs. The ethanol yield is described by the following equation:

$$\begin{aligned}
&Yield\ (gal\ pure\ ethanol) \\
&= \frac{gal\ pure\ ethanol}{dry\ MT\ C6\ sugar} \\
&\times \left(\frac{g\ VS}{kg\ wet\ feedstock} \times kg\ wet\ feedstock \times \frac{kg\ VS}{1000\ g\ VS} \times \frac{g\ C6}{kg\ VS}\right. \\
&\left.\times \frac{1\ MT\ C6}{1000000\ g\ C6}\right) + \frac{gal\ pure\ ethanol}{dry\ MT\ C5\ sugar} \\
&\times \left(\frac{g\ VS}{kg\ wet\ feedstock} \times kg\ wet\ feedstock \times \frac{kg\ VS}{1000\ g\ VS} \times \frac{g\ C5}{kg\ VS}\right. \\
&\left.\times \frac{1\ MT\ C5}{1000000\ g\ C5}\right)
\end{aligned}$$

Conversion efficiencies in gallons of ethanol per dry MT of C5 and C6 sugars were multiplied by the amount of C5 and C6 sugars respectively in the wet household organic material inputs, then added together to get total gallons ethanol yield.

First, for each feedstock the volatile solids (VS) content is multiplied by the amount of wet feedstock going through the SSF pathway. The resulting mass of VS is multiplied by the amount of C5 and C6 sugars per kg of VS in each feedstock. Conversion factors were applied to convert reported feedstock C5 and C6 sugar contents from g sugar/kg VS to MT sugar/kg VS. The conversion efficiency of C5 and C6 sugars from inputs is 1.95 and 1.91 gallons of ethanol per dry MT (US DOE 2009).

Carbon dioxide yield is based on the local SSF process which produces 1 mole of CO_2 gas per mole of pure ethanol produced. It is known that 0.9565 kg of CO_2 is produced for every 1 kg of ethanol (Ebner et al. 2014) in the local SSF process.

Compost and animal feed are produced from the residual solids that are not converted to CO_2 or ethanol. 25% of the residual solids are used to produce compost and 75% are used to produce animal feed (Ebner et al. 2014). A precursor measure of residual solids is calculated in order to find the dry compost and animal feed yields. Residual solids are the sum of the products of feedstock throughputs and their total solids content, minus the mass of CO_2 and Ethanol produced. The calculation is below:

$$Residual\ solids\ (kg) = \left(food\ (kg) \times \frac{kg\ TS}{kg\ food} + yard\ trimmings\ (kg) \times \frac{kg\ TS}{kg\ yard\ trimmings} + compostable\ paper\ (kg) \times \frac{kg\ TS}{kg\ compostable\ papaer}\right) - \left(ethanol\ (kg) + CO_2(kg)\right)$$

Dry compost and animal feed yields are the products of residual solids and their respective percent allocation (25% and 75%). From there, moisture is added into both dry compost and dry animal feed to represent marketable products. The amount of water needed is found by multiplying each of the dry masses by the finished moisture content. Finished compost is made up of 1 kg of water and 1 kg dry compost (i.e. 50% moisture) (Ebner et al. 2014), while finished animal feed is made up of 12 kg water per 88 kg of dry feed (i.e. 12% moisture) (Alibaba 2014). In the case of compost, the moistened product is multiplied by a factor accounting for mass loss through volatilization (and other factors) equivalent to 0.53 kg finished compost/1kg of compost input (Tiquia et al. 2002).

The waste water is the liquid mass not accounted for in yielded ethanol, CO_2, compost, and animal feed minus the water used to hydrate the compost and animal feed to marketable quality. The amount of water required to account for the moisture content of the finished animal feed and compost products is subtracted from the liquid portion of the inputs. The waste water/added water calculation is below:

$$\begin{aligned} &Wastewater\ or\ added\ water\ (kg) \\ &\quad = \left(food\ (kg) + yard\ trimmings\ (kg) + compostable\ paper\ (kg)\right) \\ &\quad - \left(food\ (kg) \times \frac{kg\ TS}{kg\ food} + yard\ trimmings\ (kg) \times \frac{kg\ TS}{kg\ yard\ trimmings}\right. \\ &\quad \left. + compostable\ paper\ (kg) \times \frac{kg\ TS}{kg\ compostable\ papaer}\right) - (dry\ compost\ (kg) \\ &\quad \times \frac{kg\ water}{kg\ dry\ compost} + dry\ animal\ feed\ (kg) \times \frac{kg\ water}{kg\ dry\ animal\ feed}) \end{aligned}$$

If the production of animal feed and compost requires more water than there is remaining from the feedstock inputs, additional water is assumed to be added to the process at a rate of \$0.00331 per gallon (City of Rochester, NY 2013c). In the model, the annual water charge is only applied if the waste/added water value is negative – thus indicating a need for additional water in the process to produce the compost and animal feed. The added water cost is added to operations cost of SSF. If the waste/added water value is positive, this indicates waste water effluent and is assumed to be solids-free. Therefore, no treatment charge is applied for waste water. However, in practice, there are trace solids in the SSF effluent which may command a negligible surcharge.

AD pathway

The AD pathway yields biogas and compost. Biogas yield depends on the mass of feedstock, the VS content, and the biomethane potential (i.e. specific methane yield of the feedstock). In order to determine biogas yield in the model, feedstock mass is multiplied by VS content and biomethane potential. Finally, the volume of biogas produced is changed to the mass basis using a conversion factor (7.79×10^{-6} kg per mL). The following general equation expresses this:

$$kg\ biogas = \left(kg\ wet\ feed\ stock \times \frac{g\ VS}{kg\ wet\ feed\ stock} \times \frac{mL\ CH_4}{g\ VS}\right) \times \frac{kg}{mL\ CH_4}$$

Please refer to "input parameters" section for the actual numbers used.

The mass of inputs not converted to biogas is assumed to make up the digestate effluent from the anaerobic digestion process. The amount of digestate is the difference between total feedstock inputs and the amount of biogas produced. Since this digestate can be a compost input, finished compost yield from digestate was determined. It is assumed that the digestate is 4% moisture with a C:N of 1.5 (InSource Energy 2010). The mass of digestate converted to finished compost is calculated in the same way as for the dedicated commercial composting process – using average yield values related to moisture content and C:N from triangular distributions, and then applying the efficiency factor. This calculation is expressed below:

$$\begin{aligned} finished\ compost\ (kg) \\ &= \left(total\ mass\ of\ feed\ stock\ inputs\ (kg) - \ biogas\ produced\ (kg)\right) \\ &\times \left(\frac{\%\ yield\ given\ digestate\ \%\ moisture + \%\ yield\ given\ digestate\ C\!:\!N}{2}\right) \\ &\times \frac{kg\ finished\ compost}{kg\ digestate} \end{aligned}$$

Similarly to the composting pathway, waste was calculated to account for the mass of feedstock material that remains as unfinished compost and emissions from AD compost production. The composting waste from the AD process is equivalent to the difference between the total digestate (i.e. compost feedstock) and the amount of finished compost produced.

c. Results and discussion

c.1 Total profits of the organic material management system

In the baseline, the overall profit for the system was $2,990,000. Total revenues were $5,400,000 (with $550,000 from tipping fees and $4,850,000 from net product sales). Total costs amounted to $2,410,000 (with $930,000 from operations, 610,000 from capital, and $870,000 from material trucking). Anaerobic digestion was profit maximizing for the excess food. By processing all of 16,600 MT of excess food, the anaerobic digestion pathway garnered a $1,730,000 profit. The commercial composting pathway was profit maximizing for compostable paper, and had $600,000 in profits by processing 6,570 MT of the material. SSF was profit maximizing for yard trimmings, and had $620,000 of profit by processing 4,060 MT. None of the material was sent to the landfill with gas capture pathway to maximize profit.

As Figure 5.7 shows, the vast majority of revenue in a profit-maximizing system comes from product sales. Of all HHOM management system revenues, 10% were from tipping fees and 90% were from product sales. This contrasts sharply with the current system, where private revenues are generated primarily by landfill tipping fees. A system that brings in revenue mainly with tipping fees misses out on the environmental benefits of offsetting the environmental impacts (i.e. embodied energy) from production of goods that would be made from virgin materials as opposed to waste materials.

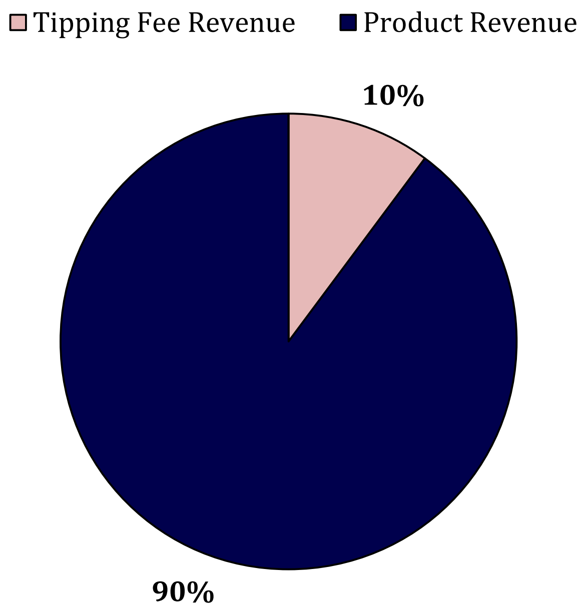


Figure 5.7: Percent share of revenue from tipping fees and product sales in baseline profit-maximizing material management system

The anaerobic digestion pathway brought in the highest gross profit in the baseline profit-maximizing system (59% of all profits) (Figure 5.8). This is due to its competitive advantage over other pathways in profitably exploiting excess food, which accounts for 61% of the household organic material stream (compared to only 15% for yard trimmings and 24% for compostable paper). The material niches occupied by SSF and composting pathways – yard trimmings and compostable paper respectively – were relatively small compared to anaerobic digestion. This limited their share of profitability in the overall system. However, SSF was the most profitable with its niche material on a $/kg basis, turning in $0.15/kg yard material compared to anaerobic digestion's $0.10/kg food and composting's $0.09/kg compostable paper.

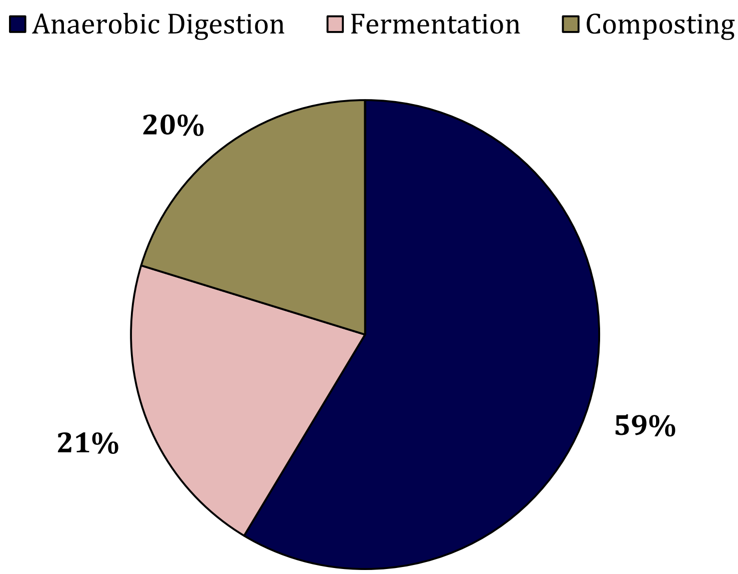


Figure 5.8: Percent share of total profit from available pathways in baseline profit-maximizing material management system

Profitability varied considerably depending on feedstock and processing pathway. As Table 5.7 shows, out of the feedstocks, yard trimmings had the highest profitability (shown in green) in terms of average profit (0.071 $/kg) and pathway maximum profit ($0.153/kg for SSF). Compostable paper was the lowest (shown in red) in terms of average profit ($0.041/kg) and pathway maximum profit ($0.091/kg for composting). Yard trimmings were 1.7 and 1.3 times more profitable on average than food and compostable paper. For food specifically, anaerobic digestion was over 2 times as profitable as the second most profitable pathways (landfill and composting), and nearly 6 times as profitable as SSF. As previously mentioned, the model baseline for AD assumed a scenario with on-site electricity generation for grid feed-in. Under the scenario where biogas is cleaned up and sold for off-site use, AD had negative profitability for each feedstock and thus is not economically viable. Compostable paper was optimized by commercial composting, with it being 1.3 times more profitable than SSF, and nearly 7 times more profitable than landfill with gas capture. Anaerobic digestion had a negative profit for compostable paper, which was the only case in which there was negative profitability for processing a feedstock. In the case of yard trimmings, SSF was 1.4 times as profitable as the next most profitable, anaerobic digestion. It was far ahead of composting and landfill with gas capture, being 22 and 12 times more profitable respectively.

Table 5.7: Profitability (in $/kg feedstock processed) of management pathways, baseline case

Pathway	**Baseline profitability ($ per 1 kg feedstock)**		
	Excess food	Yard trimmings	Compostable paper
Landfill with gas capture	0.046	0.013	0.013
Anaerobic digestion	0.104	0.112	-0.008
SSF	0.029	0.165	0.081
Composting	0.046	0.007	0.091
Average	0.056	0.074	0.044

Biomethane potential testing results for anaerobic digestion pathway

Profitability for the anaerobic digestion pathway was based in part on the results of biomethane potential (BMP) tests for each feedstock (see Table 5.8 below). The baseline model utilized the average BMP recorded from each feedstock co-digested with manure, in accordance with the current operations at the model AD process and AD best practices (EPA 2014).

Table 5.8: Results of household organic feedstock biomethane potential tests

Sample feedstock(s)	Total solids (%w/w)	Volatile solids (%w/w)	Avg. BMP (mL CH_4/g VS)
compostable paper : household food	96%	98%	413
compostable paper	96%	98%	375
compostable paper : manure	51%	94%	370
household excess food : manure	51%	94%	359
compostable paper : household food : manure	67%	95%	342
compostable paper : household food	96%	98%	327
household excess food	96%	98%	294
manure (control)	7.50%	89%	205

c.2 Total costs of the organic material management system

On the cost side of the profit-maximizing household organic material management system, there is relatively even distribution between share of costs from processing operations, capital financing, and material trucking (Figure 5.9). Operations costs are the largest share overall ($932,000 or 39%) followed by trucking ($866,000 or 36%) and finally capital ($614,000 or 25%). Based on this information, there is no singular cost barrier to the implementation of the profit-maximizing system. There is potential variance in both the operations and trucking costs. It is important to note that this model assumed HHOM was source separated. If mechanical separation was used instead, then operations cost would increase considerably and dominate total system costs.

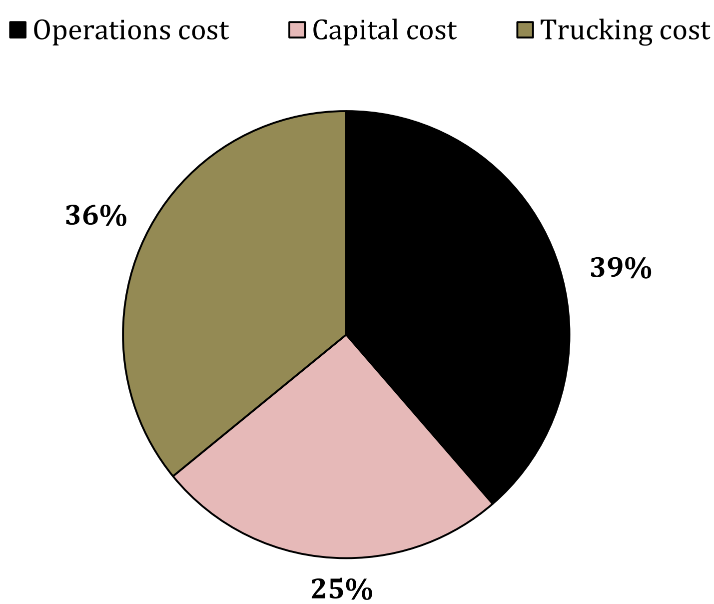


Figure 5.9: Percent share of total costs from operations, capital financing, and trucking in baseline profit-maximizing material management system

d. Sensitivity analysis

The sensitivity analysis focused on mapping and identifying the tipping points for key parameters in the model where changes in the optimal feedstock management pathways could be observed. For each feedstock, tradeoffs were examined between management pathways that differed by less than 250% in baseline profitability ($/kg). Thus for excess food, tradeoffs were investigated between AD, composting, and landfill with gas capture. For yard trimmings analysis focused on AD and SSF, and for compostable paper it was composting and SSF.

The following three sections examine the implications of pathway tipping points in depth for all three feedstocks and their key parameters. Table 5.9 below is a high-level summary of the findings. Interpretations are found in the next three sections (e.1-e.3).

Table 5.9: Summary of pathway tipping points for key model parameters

Feedstock	Baseline optimal pathway	Key parameter name	Baseline pathway key parameter value	%Δ key parameter from baseline to switch pathway	New pathway
Excess food	AD	Landfill tipping fee	60 ($/short ton)	90	Landfill with gas capture
		Pathway product revenue	0.195 ($/kg wet feedstock)	-35	Landfill with gas capture
		Trucking cost	0.032 ($/kg wet feedstock)	180	Landfill with gas capture
Compostable paper	Composting	Compost price	0.33 ($/kg compost)	-10	SSF
		Compost marketing factor	0.93	-10	SSF
		Total solids	0.54 (kg TS/ kg wet feedstock)	5	SSF
		C:N ratio	18.7	-25	SSF
Yard trimmings	SSF	Animal feed price	250 ($/MT)	-50	AD
		Ethanol price	1.58 ($/gal)	-40	AD
		Yard trimming biomethane potential	122 (mL CH_4/kg VS)	20	AD

e.1 Food feedstock

Tipping fee revenue was an important point for sensitivity analysis, considering the wide use of landfill tax and/or organic ban policy to encourage alternative pathways such as anaerobic digestion, composting, and SSF. As Figure 5.10 shows, the landfill tipping fee would have to increase by 90% in order for the landfill food management pathway to be as profitable as anaerobic digestion. This suggests that a landfill tax would be unnecessary for anaerobic digestion to be competitive – in the baseline case with current landfill tipping fees.

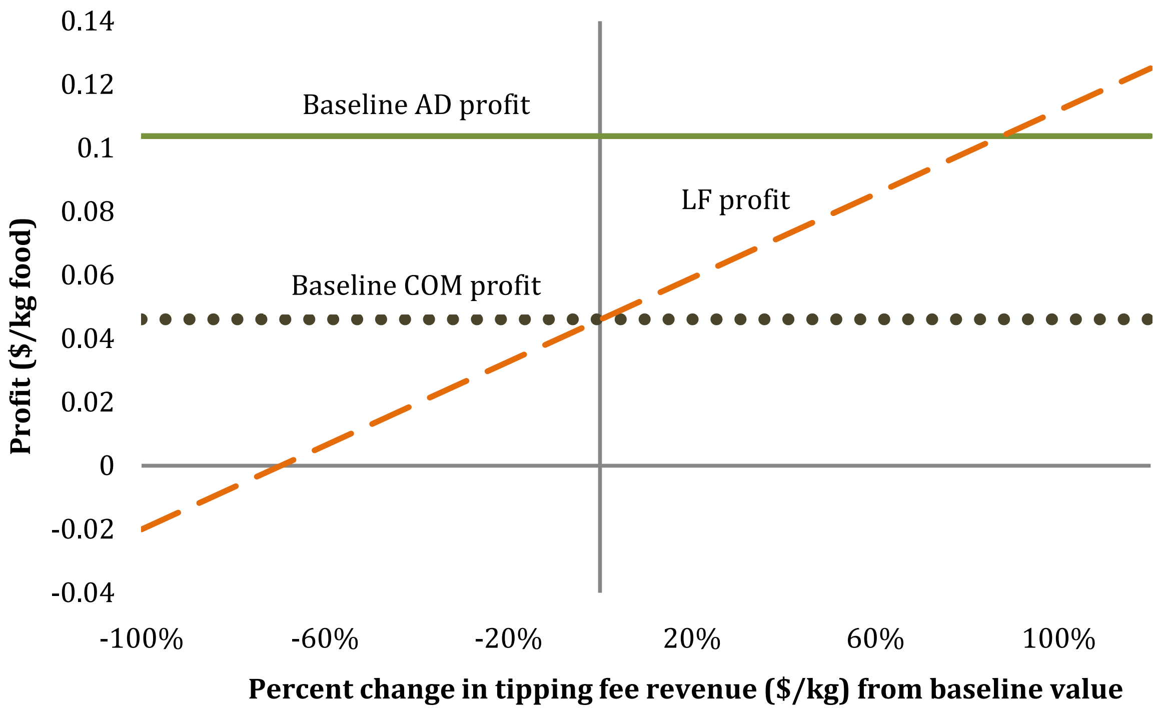


Figure 5.10: Landfill food management pathway profit ($/kg food) relative to changes in tipping fee revenue ($/kg) from baseline, holding constant anaerobic digestion and composting pathway revenues ($/kg food)

Tipping fees are the major contributor to revenue for the incumbent food management pathway of landfill with gas capture, and also play a role in the profits of the other pathways. As Figures 5.11 and 5.12 show, the anaerobic digestion pathway is much less sensitive to changes in tipping fee revenue compared to the landfill. Even if anaerobic digestion tipping fees are reduced to $0 (i.e. 100% reduction), anaerobic digestion is still more profitable than landfills. This suggests that low tipping fees could be a sustainable point of entry for anaerobic digestion developers hoping to get municipalities to switch their management pathway, since overall anaerobic digestion profitability is still positive and competitive even in the absence of tipping fee revenue. Inversely, anaerobic digester developers should not expect to most effectively increase profitability by increasing the price of tipping fees.

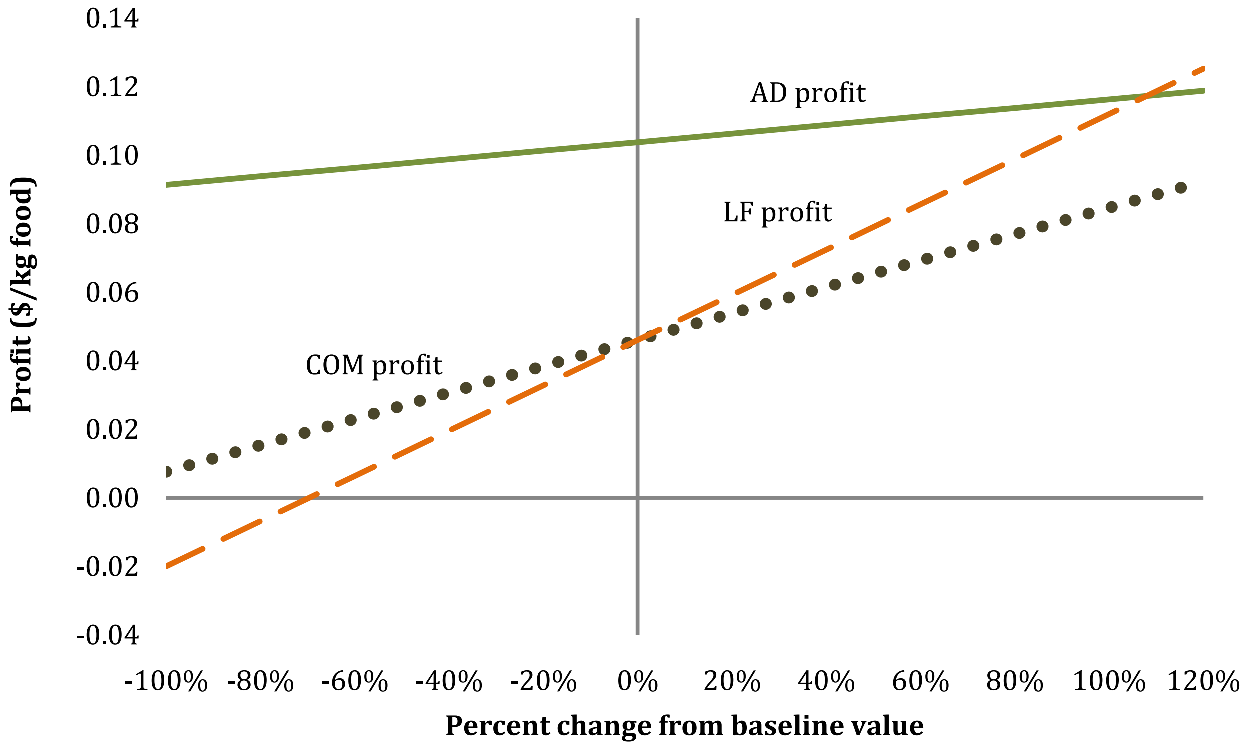


Figure 5.11: Food management pathway profits ($/kg food) relative to changes in tipping fee revenue ($/kg) from baseline

LF tipping fee revenue ($/kg)

percent change from baseline value

LF \ AD	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	130
130	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF
120	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF
110	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	AD	AD
100	LF	LF	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD
90	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
80	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
70	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
60	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
50	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
40	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
30	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
20	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
10	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
0	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
-10	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
-20	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD

AD tipping fee revenue ($/kg) percent change from baseline value

Figure 5.12: Area plot of profit maximizing food management pathway relative to changes in LF and AD tipping fees ($/kg) from baseline

Trucking costs were important for sensitivity analysis because a number of assumptions used in the FreightMetrics calculator that produced the trucking cost estimates were unverified (i.e. driver wage, truck capacity, truck cost). As Figure 5.13 shows, the landfill pathway is not affected by trucking costs in this model, as all of the material is currently brought to the landfill site by the City of Rochester, NY. It was assumed that the other pathways would require their own trucking for collection from households. Anaerobic digestion, commercial composting, and SSF were all affected equivalently by increases in trucking costs. In order for the leading food management pathway (anaerobic digestion) to reach parity with landfill, trucking costs would require a 180% increase from the baseline value. Any decrease in trucking costs from the baseline increased the profitability of non-landfill pathways. A decrease of just 5% was enough to elevate composting above landfill. A 100% decrease would be required to elevate SSF above landfill. These results indicate that trucking is not expected to be a major cost barrier preventing anaerobic digestion from being the most profitable food management pathway.

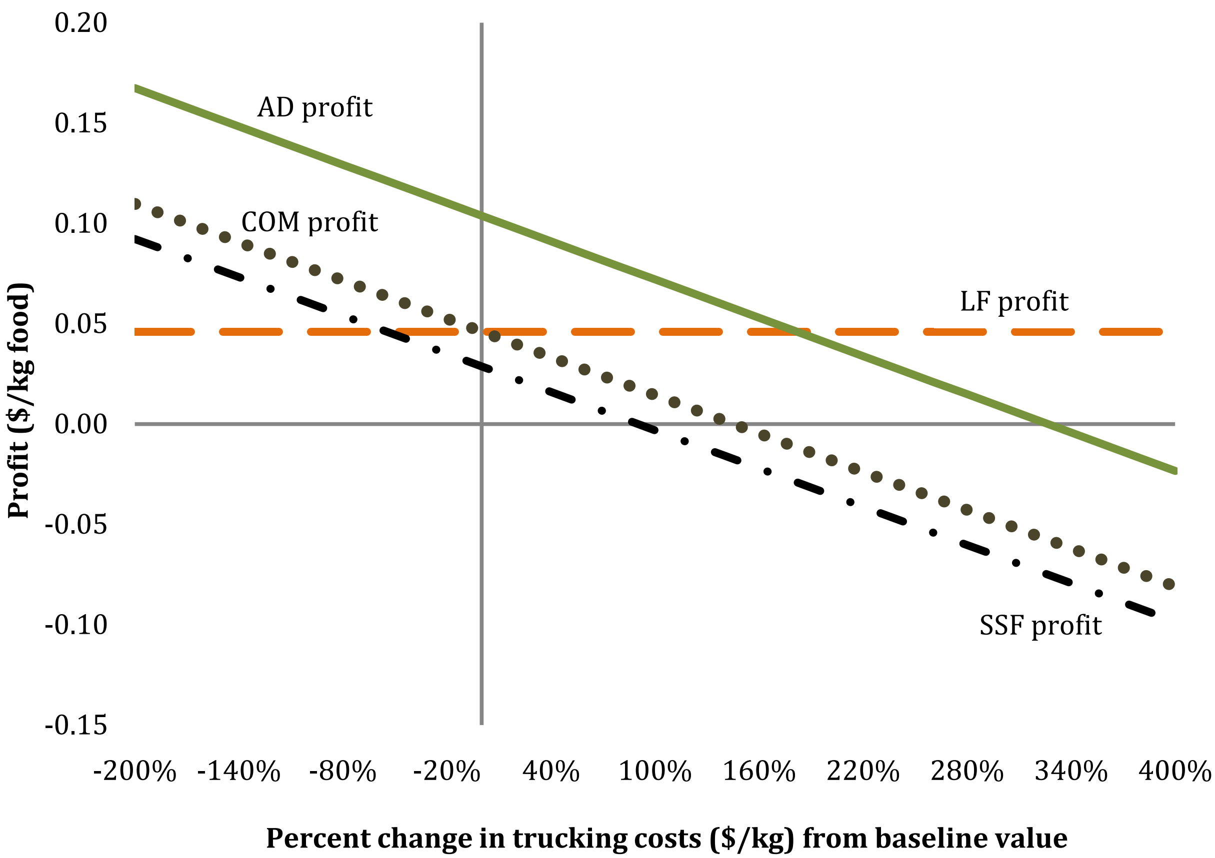


Figure 5.13: Food management pathway profits ($/kg food) relative to changes in trucking costs ($/kg) from baseline

While tipping fees have a small effect on anaerobic digestion, the pathway is relatively sensitive to changes in product revenue. At a 35% decrease in product revenue (approximately \$0.4/kwh), landfill reached profit parity with AD. At a further 50% decrease, anaerobic digestion is at parity with composting, and inferior to landfill (Figure 5.15). On the other hand, expected increases in product revenue from anaerobic digestion (i.e. higher \$/kWh electricity produced over relatively low wholesale rate of \$0.06/kWh) would greatly increase AD profitability. These findings suggest that developers of anaerobic digestion should focus their efforts on making the biogas production process run smoothly to achieve a high capacity factor – or else face quickly declining profits. Optimistically, net metering subsidies in New York State have been approved which will offer greater than \$0.06/kWh sale price for grid feed-in electricity from anaerobic digestion (DSIRE 2014). They also suggest that landfill gas revenue is relatively small, and that even large expected increases in the efficiency of landfill gas technology will not elevate the pathway over its competitors. It is likely that the technology in all pathways will advance, but larger profit gains will be achieved in the non-landfill pathways due to the small share of total landfill revenue from its sole landfill gas product (see Figure 5.14 on next page).

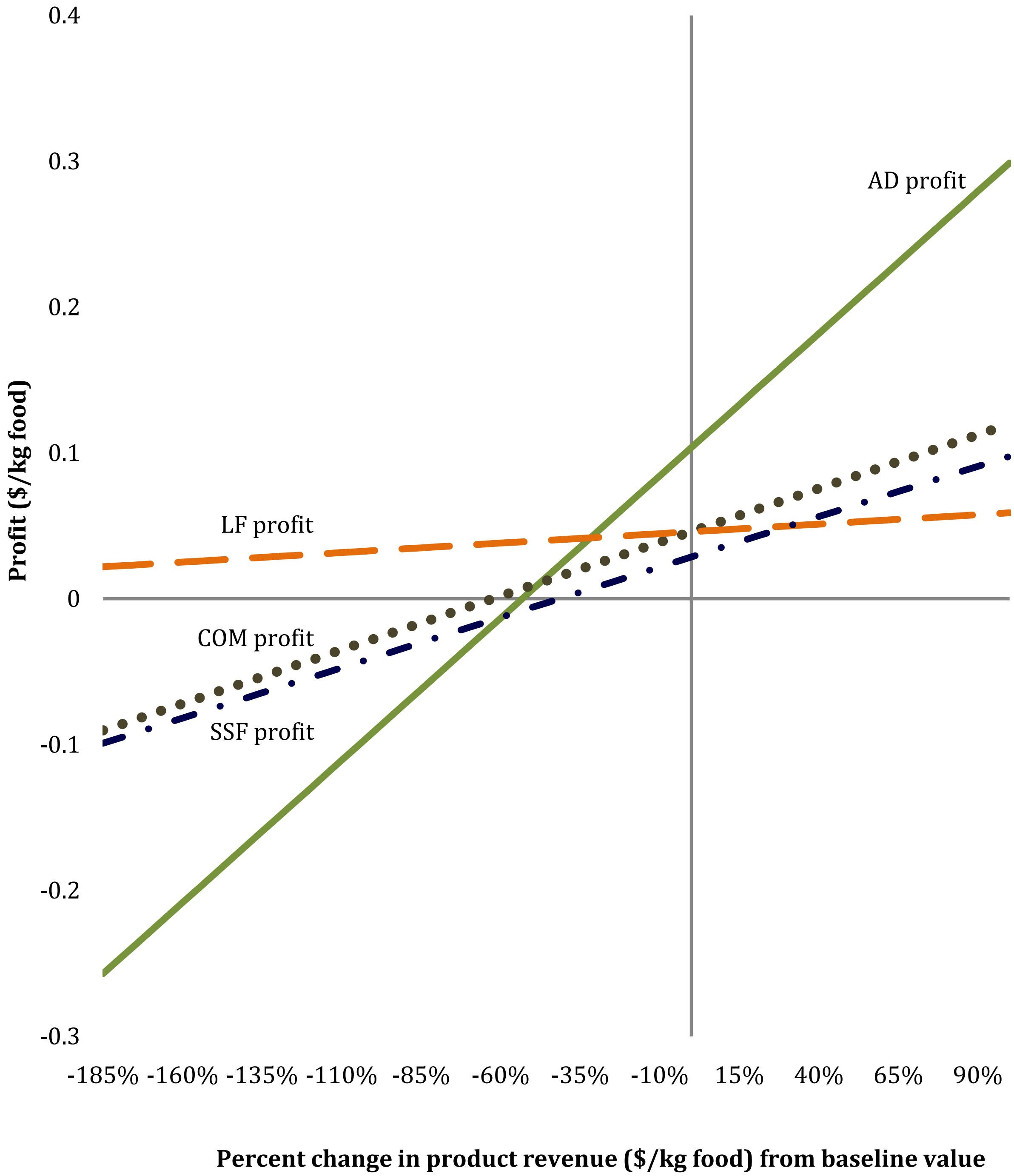


Figure 5.14: Food management pathway profits ($/kg food) relative to changes in product revenue ($/kg food) from baseline

Trucking cost ($/kg) percent change from baseline value

100	LF	LF	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
80	LF	LF	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
60	LF	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
40	LF	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
20	LF	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
0	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
-20	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
-40	LF	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
-60	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
-80	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
-100	LF	LF	LF	LF	LF	LF	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD
	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100

Product revenue ($/kg food) percent change from baseline value

Figure 5.15: Area plot of profit maximizing pathway relative to changes trucking cost ($/kg) and product revenue ($/kg food)

e.2 Yard trimming feedstock

Both ethanol and animal feed is produced in high yields from the SSF pathway and both produce considerable revenue. Sensitivity analysis was required to examine the relative importance of each product to the overall profitability of the SSF pathway. As Figures 5.16 and 5.18 show, it would require a ~60% reduction in SSF animal feed market price in order to bring SSF to price parity with AD. By comparison, only a ~40% reduction in ethanol price would have the same effect (Figures 5.17 and 5.18). This suggests that even though animal feed is produced in slightly higher quantities than ethanol in the process, the relatively high market price of ethanol makes it a more important product for the bottom line in the baseline case. However, the sensitivity of the products to prices are similar, and SSF pathway developers could mitigate risk by optimizing production for the product which has less market price volatility, or greater certainty of deal flow for product purchases.

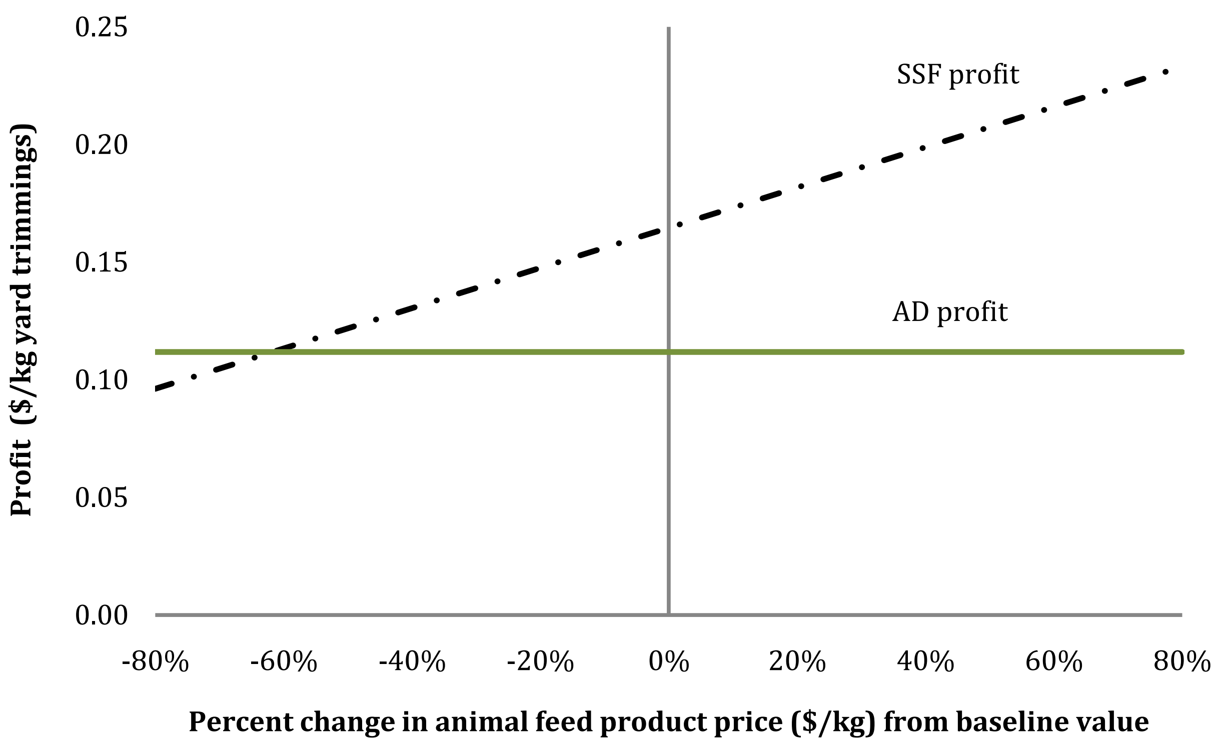


Figure 5.16: SSF and anaerobic digestion pathway profits ($/kg yard trimmings) relative to percent change in animal feed product price ($/kg) from baseline

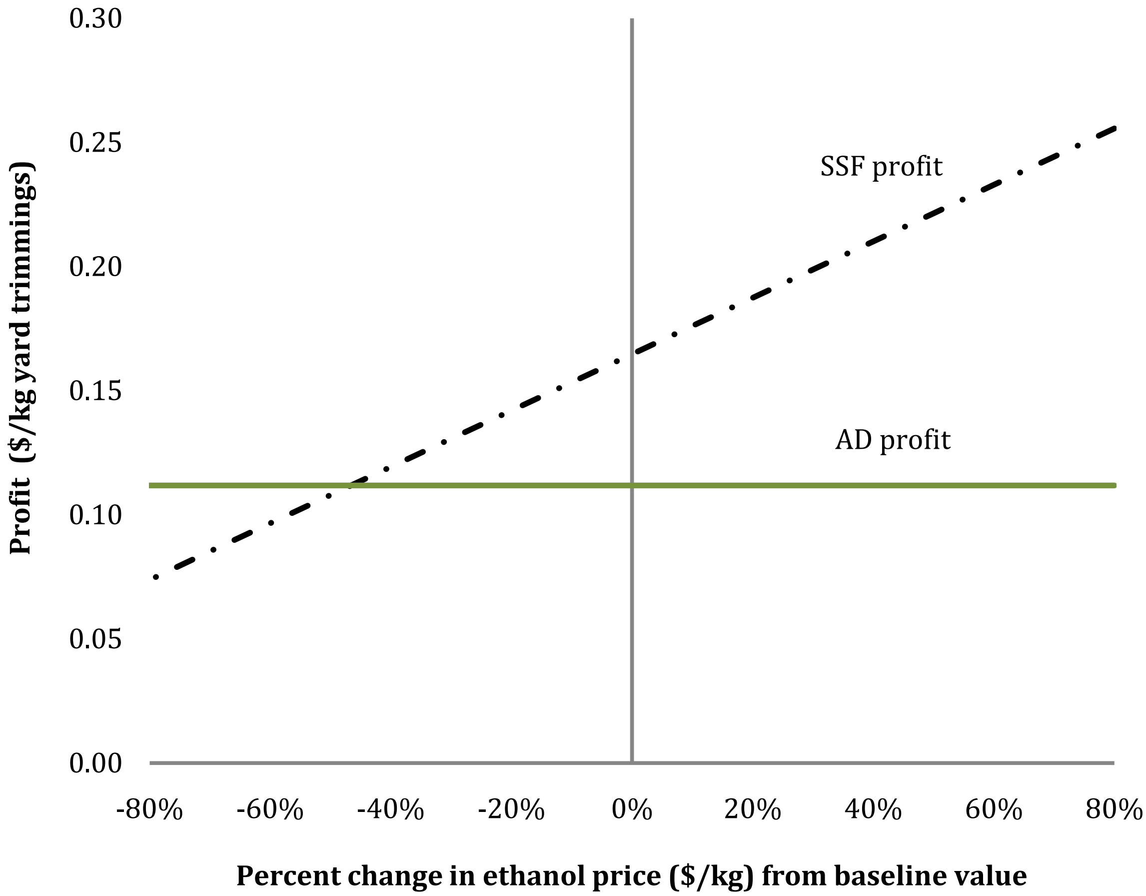


Figure 5.17: SSF and anaerobic digestion pathway profits ($/kg yard trimmings) relative to percent change in ethanol product price from baseline

Animal feed price ($/kg) percent change from baseline value

80	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
70	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
60	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
50	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
40	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
30	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
20	AD	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
10	AD	AD	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
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-20	AD	AD	AD	AD	AD	AD	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-30	AD	AD	AD	AD	AD	AD	AD	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-40	AD	AD	AD	AD	AD	AD	AD	AD	AD	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-50	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-60	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	SSF	SSF	SSF	SSF	SSF	SSF
-70	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	SSF	SSF	SSF	SSF	SSF
-80	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	SSF	SSF	SSF
	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80

Ethanol price ($/kg) percent change from baseline value

Figure 5.18: Area plot of profit maximizing yard trimming management pathway relative to percent changes in ethanol and animal feed product prices

Yard trimming feedstock sugar content required sensitivity analysis because there was no primary sample prepared for yard trimmings for the model parameters. In addition, the switch grass baseline (although it grows natively in the Rochester, NY area) has different sugar contents than other plants that would be in household yard trimmings. C5 sugars were used as a proxy for C6 sugars because they have the same mathematical relationship to yield with only slightly varying ethanol conversion efficiencies. Sensitivity analysis on sugar content was interesting because the direction of profitability changes depending on the ethanol market price. The inflection point is at \$0.55/kg (Figure 5.19). Above this price, higher sugar content corresponds to higher ethanol yields, and therefore higher profits (Figure 5.20). Below \$0.55/kg, increasing sugar content decreases overall profit of the SSF pathway (Figure 5.21). In this case, increasing sugar contents still increase ethanol yield. However, since ethanol is at a low price it is less profitable than animal feed, which is produced in a relatively large quantity from the residual solids not converted to ethanol in the SSF process. This means that SSF developers need to focus on the ethanol market price when optimizing their process for profitability. Varying only ethanol price, SSF reaches profit parity with anaerobic digestion at an ethanol price of \$0.80/gal, which is close to the lower-bound price of \$0.40/gal (Ebner et al. 2014).

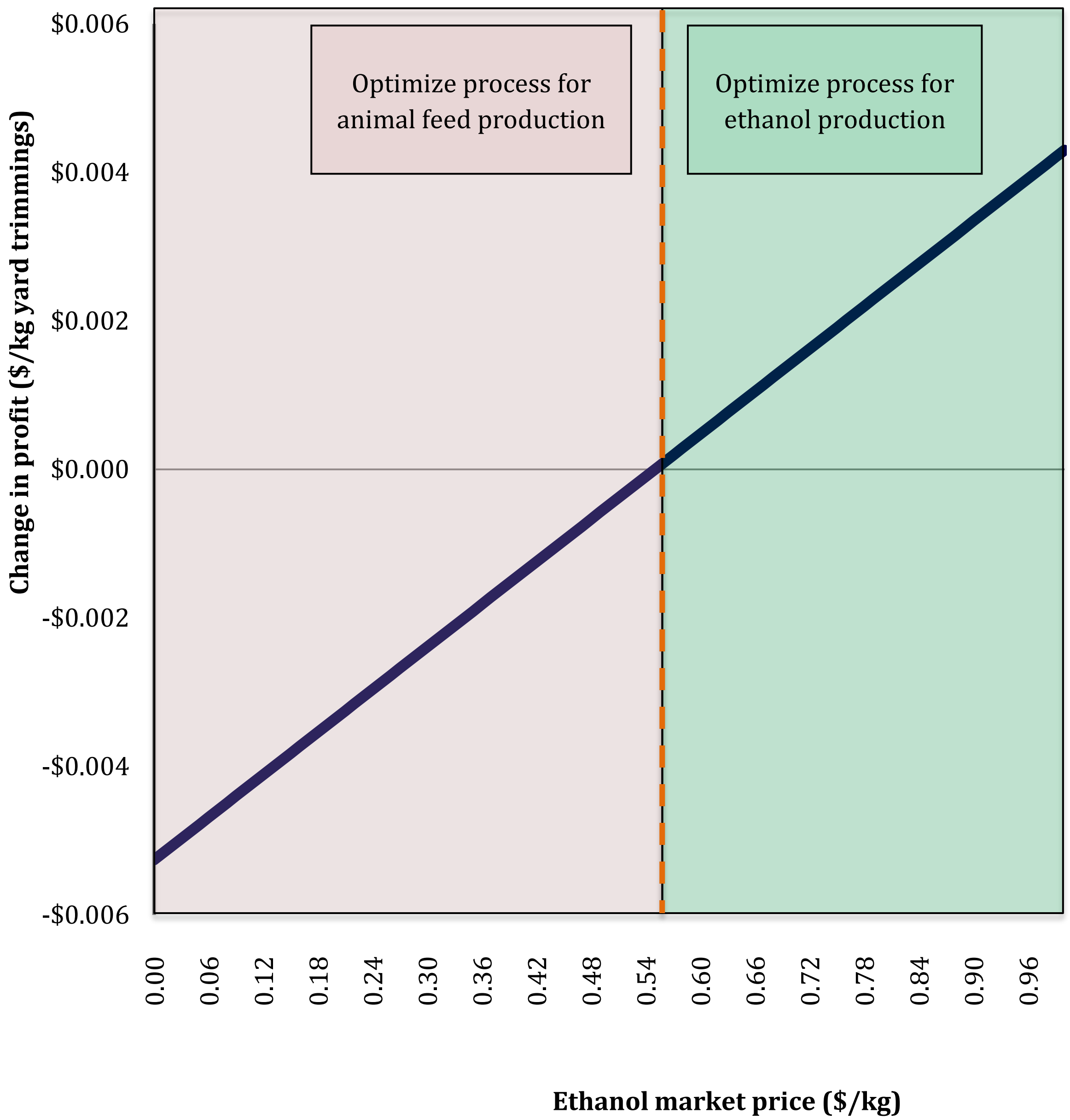


Figure 5.19: SSF pathway percent change in profit ($/kg yard trimmings) from 10% increase in C5 sugar/kg VS relative to yard trimming baseline at different ethanol prices ($/kg pure ethanol)

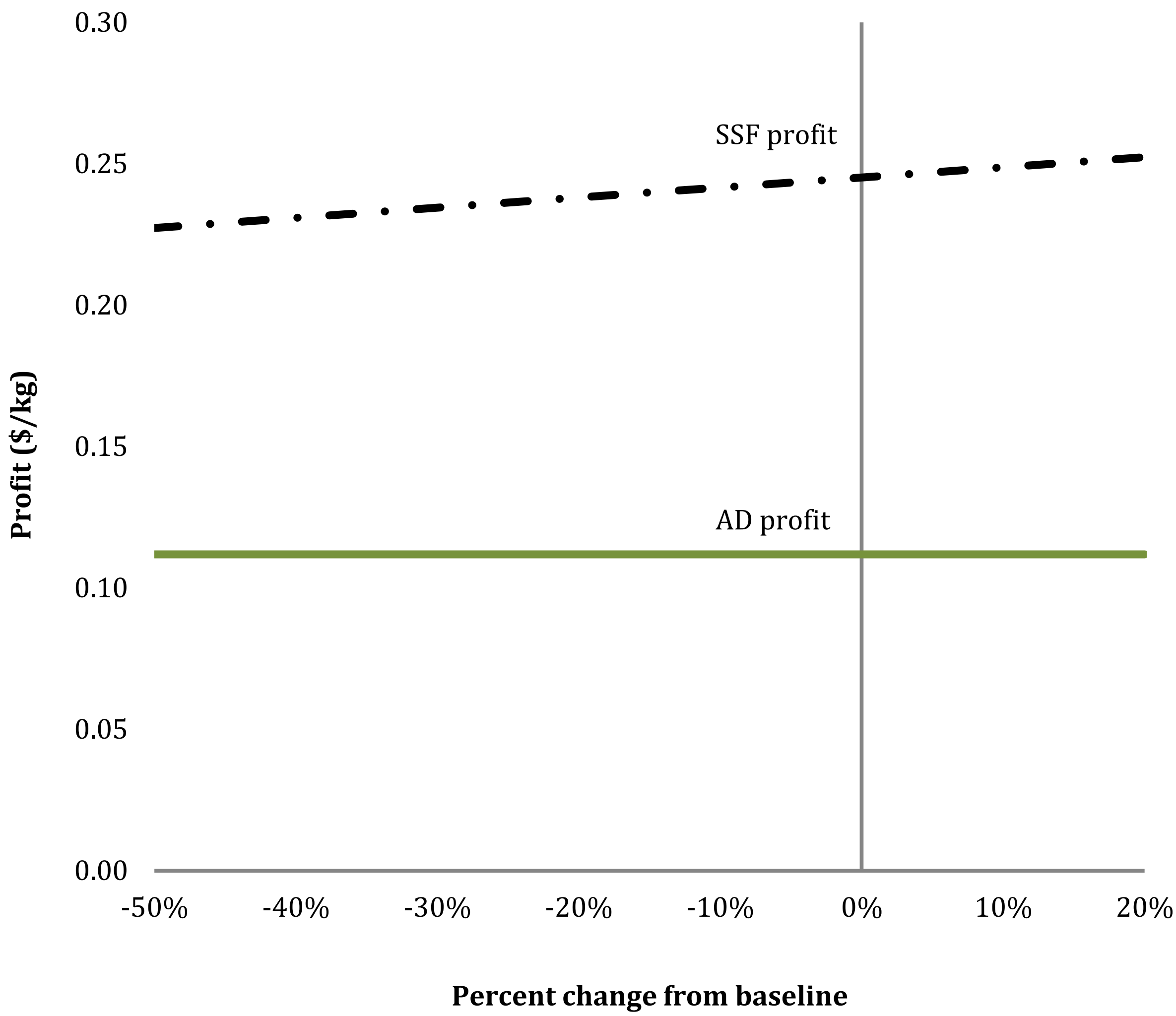


Figure 5.20: SSF and anaerobic digestion pathway profits ($/kg yard trimmings) relative to percent change in yard trimming C5 sugar content (g/kg VS) relative to baseline; assuming upper bound ethanol price ($2.75/gal)

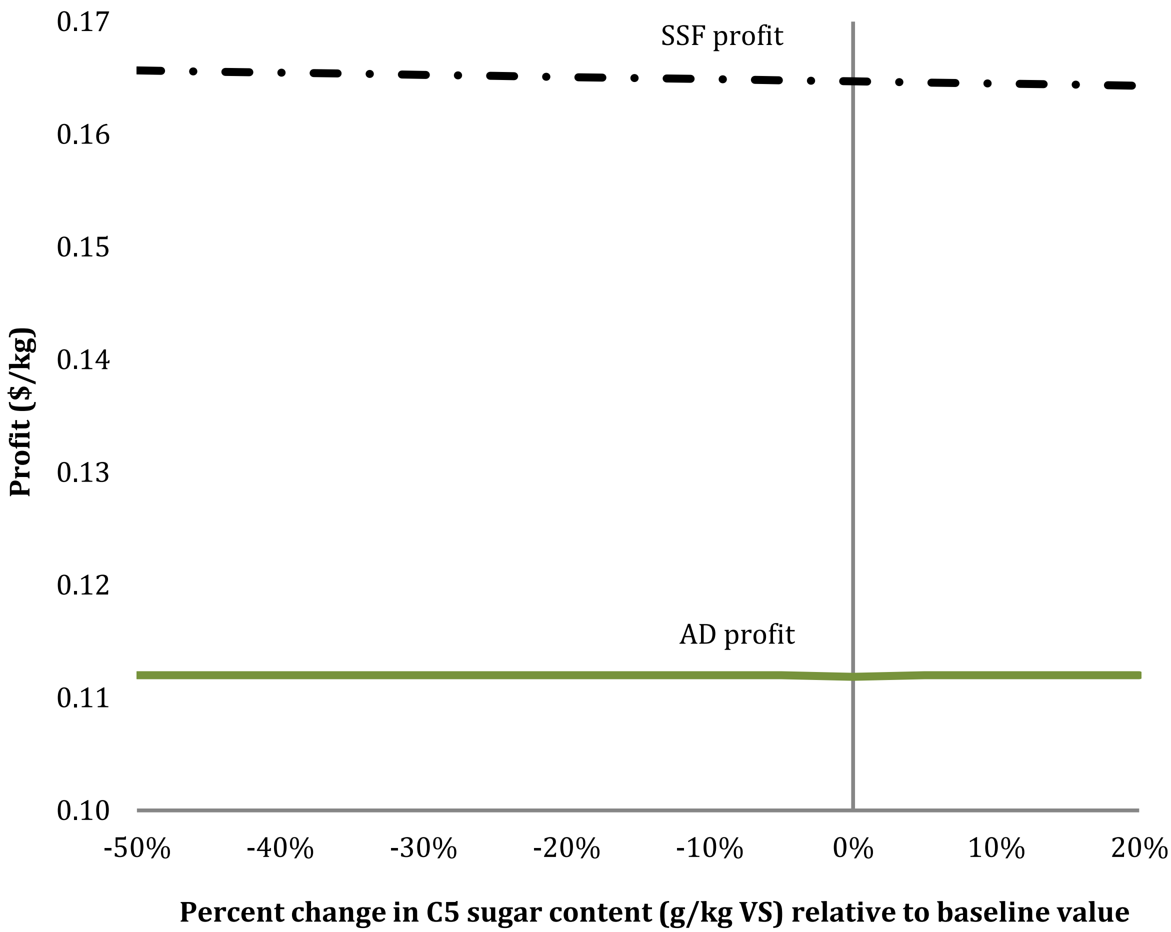


Figure 5.21: SSF and anaerobic digestion pathway profits ($/kg yard trimmings) relative to percent change in yard trimming C5 sugar content (g/kg VS) relative to baseline; assuming baseline ethanol price ($1.58/gal)

The effect of capital loan term on AD and SSF profits is another focus for sensitivity analysis since capital layouts are in the multi-million dollar range for both pathways. AD has a higher capital cost, thus it is more sensitive to changes in loan term (i.e. annual capital debt financing layouts) (Figure 5.22). In the upper bound and midpoint ethanol prices, SSF is more profitable than AD at any loan term. Only at a very short 2 year loan term with lower bound ethanol price does AD become more profitable than SSF. Even then, landfilling is still less profitable than these two pathways.

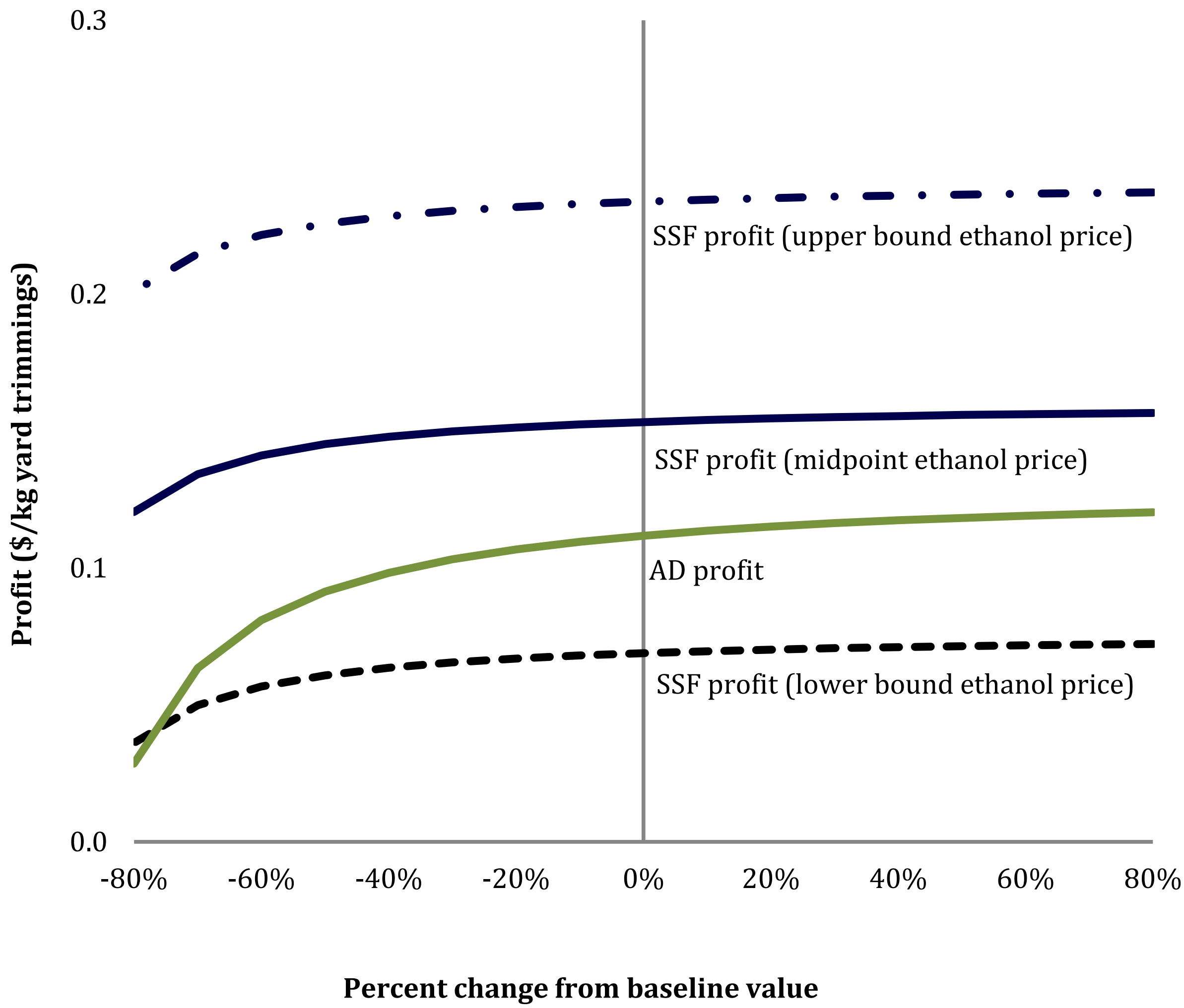


Figure 5.22: SSF and anaerobic digestion pathway profits ($/kg yard trimmings) relative to percent change in capital loan term (years); assuming lower bound, midpoint, and upper bound ethanol prices

The sensitivity of AD profit as it relates to biomethane potential (BMP) of the yard feedstock was analyzed due to the lack of primary data on BMP of yard trimmings. It would require a 30% change in the BMP of yard trimmings to bring it to parity with the leader, SSF (Figure 5.23). This means that the profit maximizing yard trimming pathway is relatively sensitive to yard material BMP. These findings suggest that care should be taken to ensure a reliable primary source BMP measurement for yard trimmings before investing in capital to manage the material in the most profitable way.

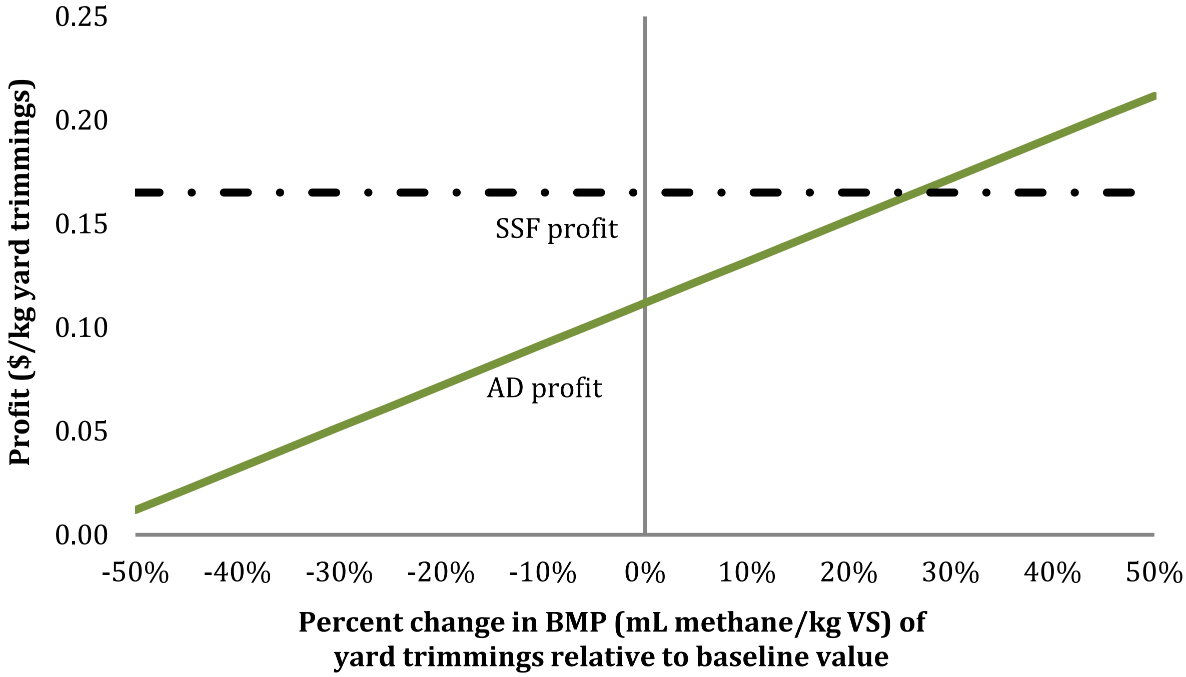


Figure 5.23: Anaerobic digestion and SSF pathway profits ($/kg yard trimmings) relative to percent changes in biomethane potential of yard feedstock (mL methane/kg VS) from baseline

AD and SSF profits are also dependent on yard trimming total solids (TS) content, and require analysis similar to BMP. SSF is slightly more responsive to changes in TS, but not enough for it to be a material difference. It would take a 70% reduction in TS for SSF, and a 50% reduction for AD to be at profit parity with landfill (Figure 5.24). Considering the relatively dry, fibrous nature of yard trimmings, this scenario is highly unlikely. It can safely be concluded that both AD and SSF are more profitable than landfill (and composting) pathways for yard material.

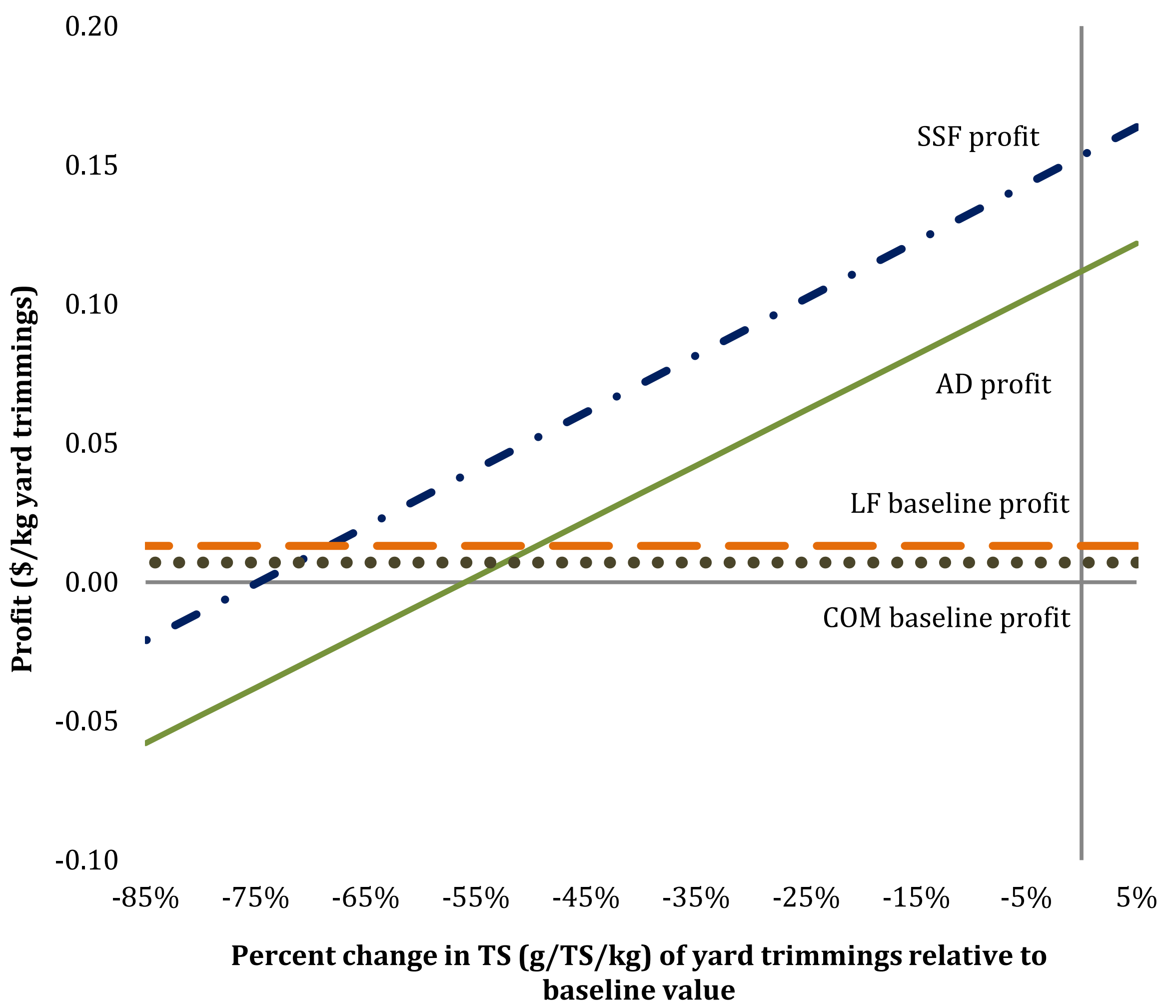


Figure 5.24: Anaerobic digestion and SSF pathway profits relative to percent changes in yard trimming feedstock total solids content (g TS/kg) from baseline

e.3 Compostable paper feedstock

Composting and SSF were the top two management pathways for compostable paper, with composting leading the way. Since the compost product is part of both pathway revenues, the sensitivity of profit to compost price was examined. The baseline compost price for SSF was one third of that of the dedicated commercial composting pathway. This is due to the lack of verification over the quality of the SSF compost. As figures 5.25 and 5.26 show, the SSF pathway is much less sensitive to changes in compost revenue than the composting pathway. After a 10% reduction in compost price from the baseline, the SSF pathway becomes the most profitable management pathway for compostable paper. On the other hand, it would take a 180% increase in compost price to bring SSF to price parity with the baseline composting price (Figures 5.25 and 5.26).

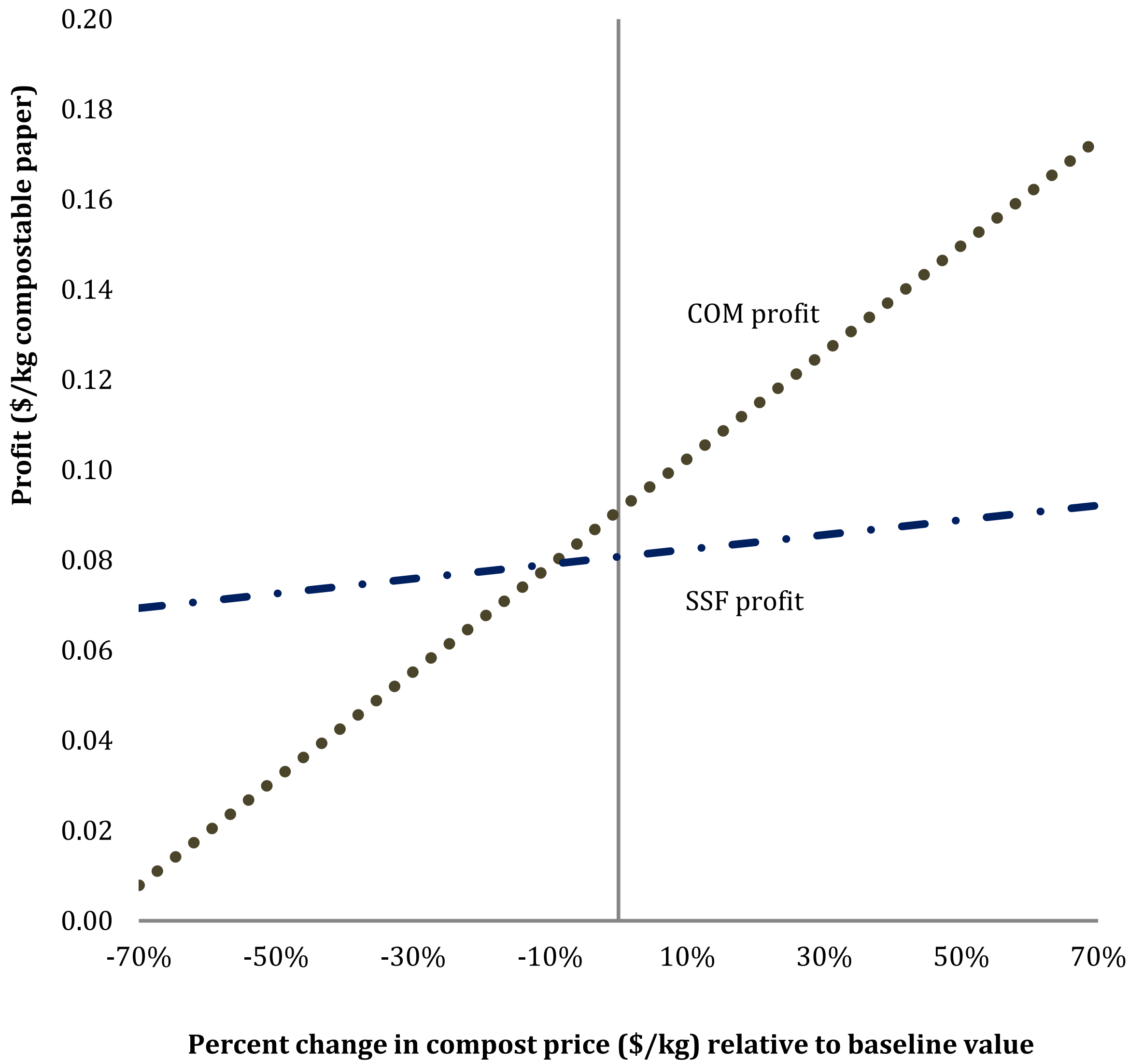


Figure 5.25: Compostable paper management pathway profits ($/kg compostable paper) relative to percent changes in compost market price ($/kg) from baseline

Compost pathway, compost revenue ($/kg compost) percent change from baseline

50	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
40	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
30	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
20	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF
10	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF
0	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-10	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-20	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-30	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-40	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-50	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
	-60	-30	0	30	60	90	120	150	180	210	240	270	300	330	360	390	420

SSF pathway, compost revenue ($/kg compost) percent change from baseline

Figure 5.26: Area plot of profit maximizing compostable paper pathway ($/kg compostable paper) relative to percent changes in compost product revenue ($/kg compost) from baseline

The difficulty of marketing and selling the products from the SSF and composting pathways are a parameter of interest. There is a high degree of uncertainty involved in product marketing due to the novelty of the SSF pathway implementation. As Figures 5.27 and 5.28 show, the SSF pathway is not nearly as sensitive to the compost marketing factor as the composting pathway. Only a 10% reduction in the marketing factor (which increases the penalty to compost revenue) renders COM less profitable than SSF. This is due to the diversified revenue stream of SSF compared to COM, AD and LF. Thus, in a local area with a strong market for compost, the composting pathway would far and away be the most profitable pathway for compostable paper. On the other hand, weak demand would favor the SSF pathway over composting.

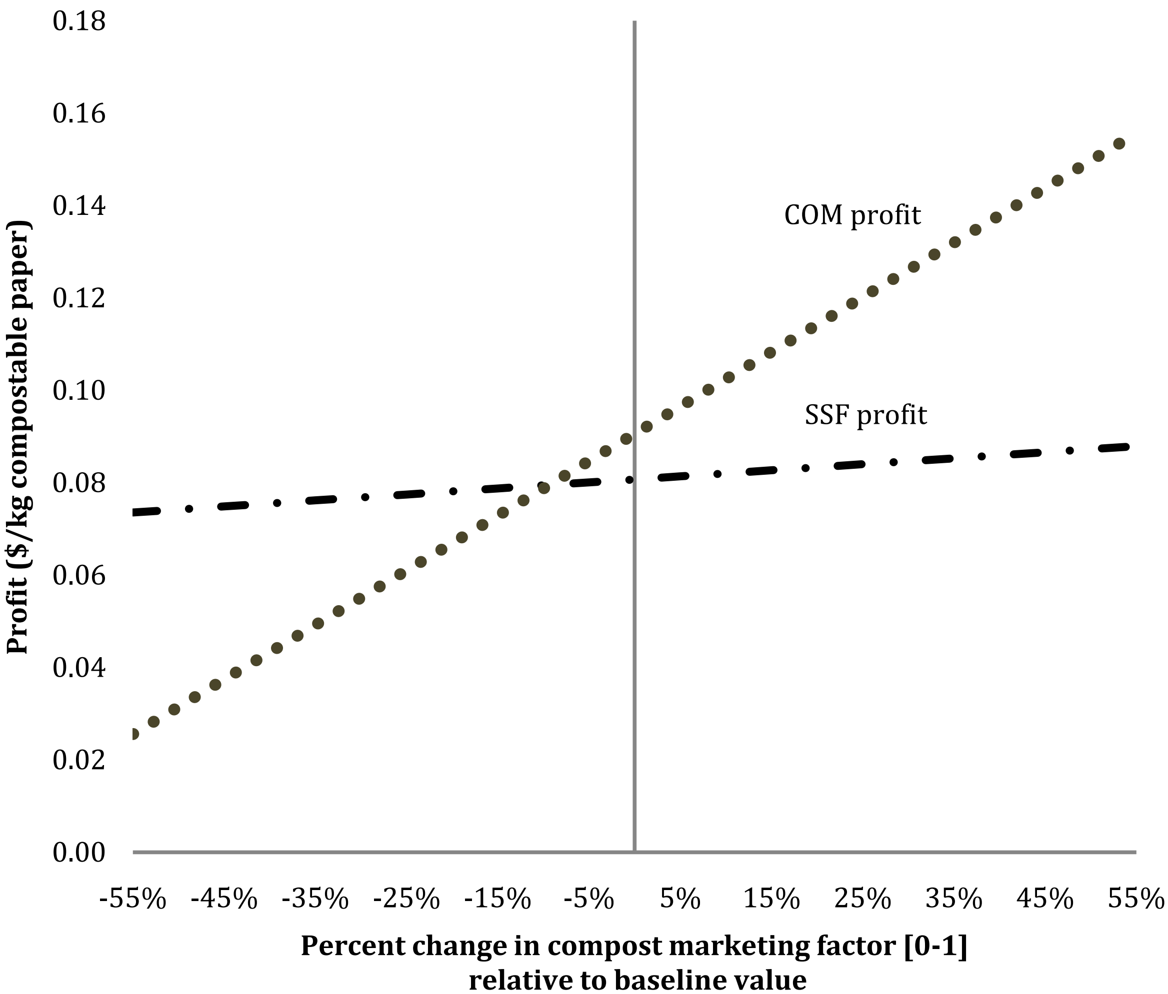


Figure 5.27: Compostable paper management pathway profit ($/kg compostable paper) relative to percent change in compost marketing factor (proportion realized revenue after sales and marketing) from baseline

SSF pathway, compost marketing factor percent change from baseline value

25	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
20	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
15	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
10	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
5	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
0	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
-5	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
-10	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
-15	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
-20	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
-25	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM
	-25	-20	-15	-10	-5	0	5	10	15	20	25

Composting pathway, compost marketing factor percent change from baseline value

Figure 5.28: Area plot of profit maximizing compostable paper pathway ($/kg compostable paper) relative to percent changes in compost product marketing factor from baseline

Similarly, sensitivity to the ethanol marketing factor was of interest. It appears that the ethanol pathway does not reach parity with the composting pathway while accounting for changes in this factor (Figure 5.29). At 25% increase from baseline, the marketing factor of ethanol is at 1. This means that revenues earned from ethanol sales in the model are not being reduced to account for marketing costs. Thus, even when selling the ethanol has no cost to the SSF business, overall SSF pathway revenues are smaller than for the composting pathway (Figure 5.30). Since ethanol is normally the primary revenue stream for SSF, this finding indicates that the composting pathway is firmly ahead of SSF as the most profitable compostable paper management pathway.

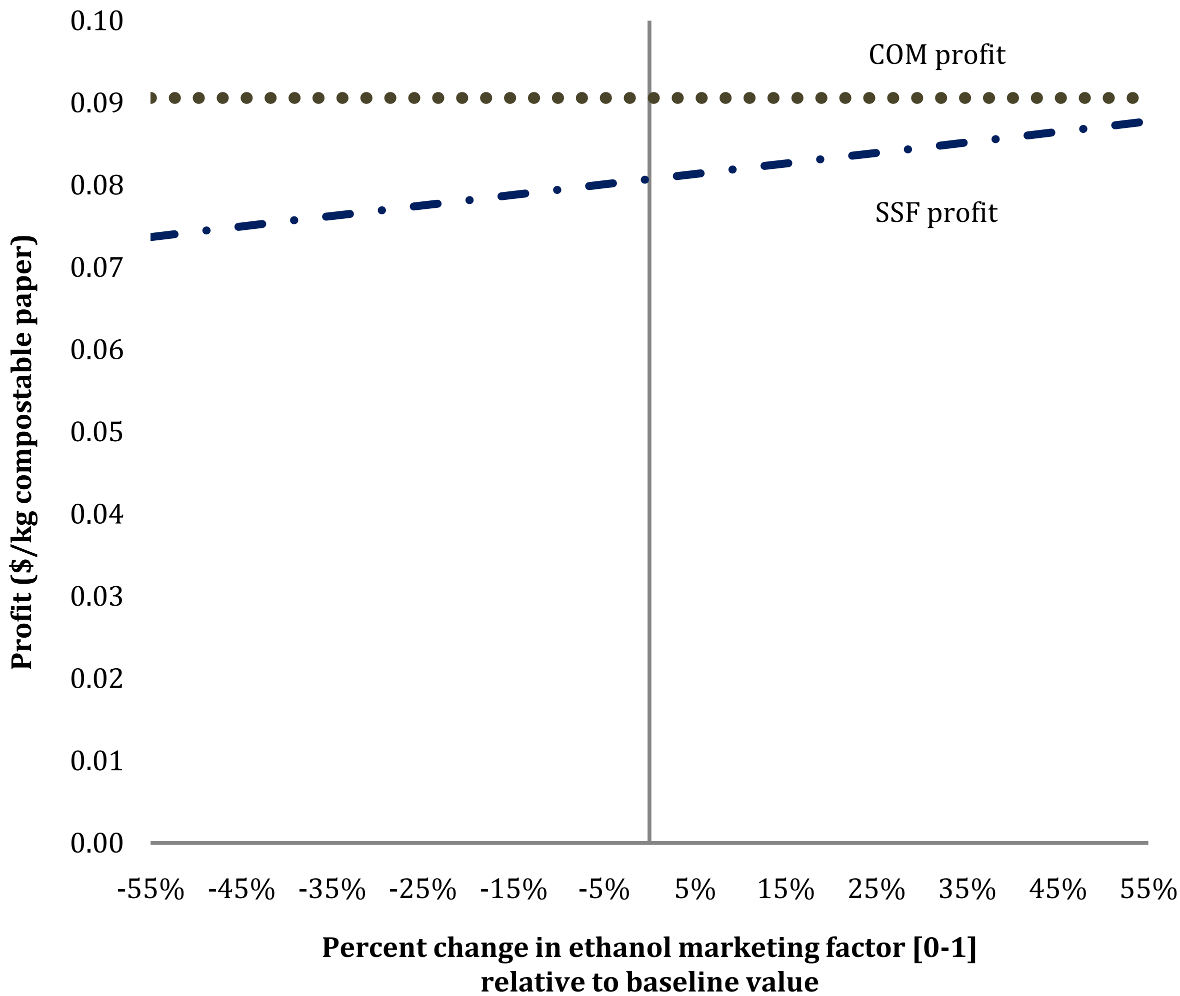


Figure 5.29: Fermentation pathway profit ($/kg compostable paper) relative to percent change in ethanol marketing factor (proportion realized revenue after sales and marketing) from baseline

SSF pathway ethanol marketing factor percent change from baseline

30	SSF	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM
25	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
20	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
15	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
10	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
5	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
0	SSF	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
-5	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
-10	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
-15	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
-20	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
-25	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
-30	SSF	SSF	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30

Composting pathway compost marketing factor percent change from baseline

Figure 5.30: Area plot of profit maximizing compostable paper pathway ($/kg compostable paper) relative to percent changes from baseline in the product marketing factors for ethanol (SSF) and compost (composting)

Total solids and C:N ratio are parameters that most strongly influence the profit of the composting pathway. TS is also a determinant of SSF profits. These feedstock parameters can vary considerably, so sensitivity analysis was required. As far as TS is concerned, it took only a 5% change in feedstock TS for composting to be at profit parity with SSF (Figure 5.31). This level of sensitivity suggests that TS is a key determinant of profit for compostable paper management pathways.

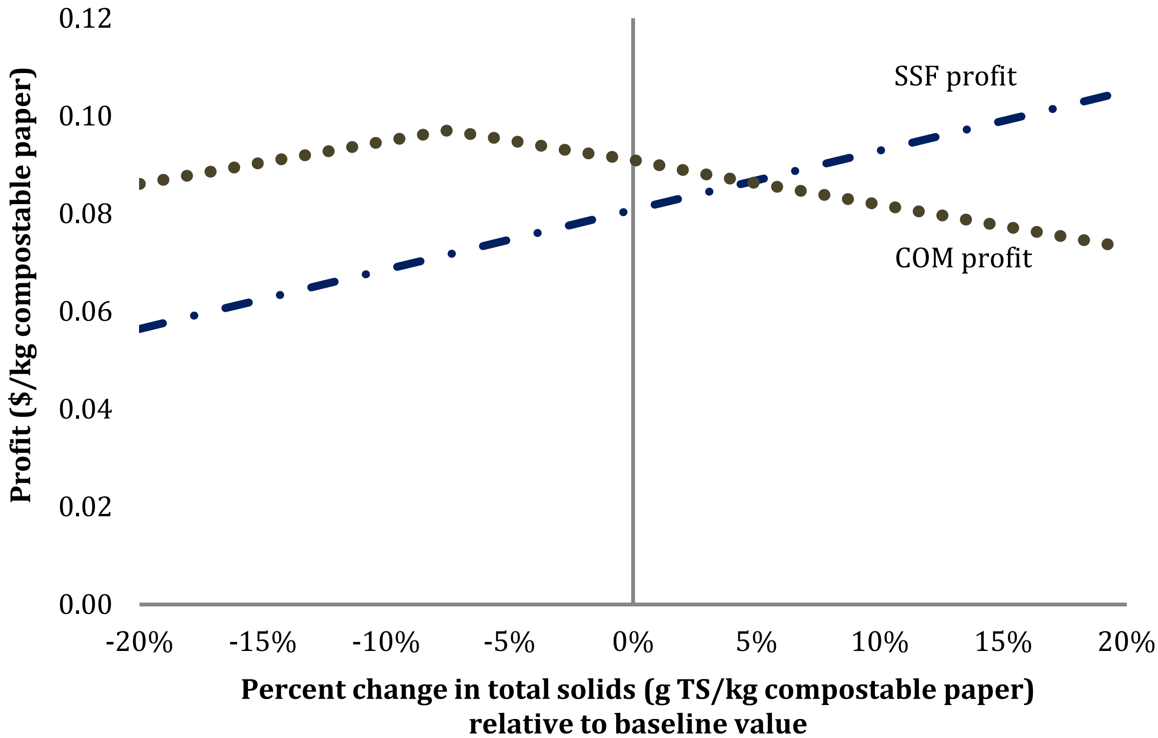


Figure 5.31: Profit ($/kg compostable paper) for SSF and composting management pathways relative to percent changes in total solids (g TS/kg compostable paper)

As for C:N ratio, the composting pathway was also sensitive. A 50% reduction in C:N ratio resulted in a 50% reduction in profit ($/kg compostable paper) (Figure 5.32; Figure 5.33). At that point, composting declined to profit parity with SSF. The results suggest that higher C:N ratios would yield much higher profits, and that profitable synergies in composting could be achieved by mixing compostable paper with yard materials that have high C:N ratios.

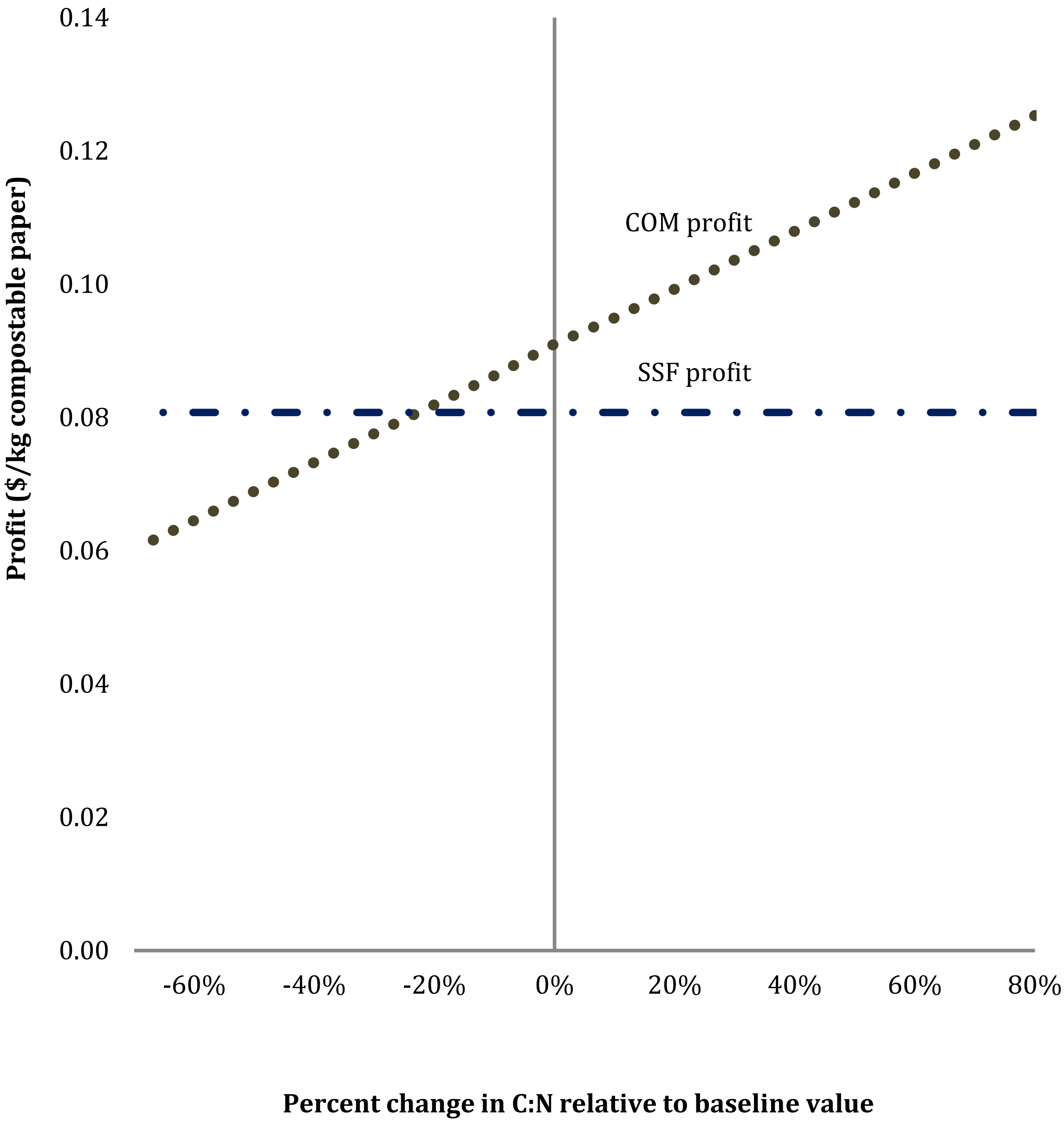


Figure 5.32: Profit ($/kg compostable paper) for SSF and composting management pathways relative to percent changes in carbon to nitrogen ratio

Compostable paper C:N ratio percent change from baseline

70	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
60	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
50	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM
40	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF
30	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF
20	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF
10	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF
0	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF
-10	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF
-20	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF
-30	COM	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-40	COM	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-50	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-60	COM	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
-70	COM	COM	COM	COM	COM	COM	COM	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF	SSF
	-20.0	-17.5	-15.0	-12.5	-10.0	-7.5	-5.0	-2.5	0.0	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0

Compostable paper total solids (kg TS/kg feedstock) percent change from baseline

Figure 5.33: Area plot of profit maximizing compostable paper pathway ($/kg compostable paper) relative to percent changes in feedstock C:N ratio and total solids from baseline

e. Conclusions

This chapter presented a profit maximization model applied to the city of Rochester, NY. Overall, the baseline model made conservative assumptions about the potential profitability of pathways that are not incumbent in Rochester, NY – namely AD, SSF, and windrow composting. In the baseline, the lower bounds were used for feedstock chemical parameters known to positively correlate with profitability ($/kg processed) in AD, SSF, and COM pathways. Thus, the model assumes lower quality feedstocks in the city of Rochester, NY for processing via AD, SSF, and COM. In addition, the trucking costs were pessimistic, as 70 miles was assumed to be the distance traveled in one day. Currently, the distance traveled to the one non-landfill commercial pathway operating in the city of Rochester, NY (i.e. Community Composting, LLC) is 60 miles. Half of that distance (30 miles) is covered trucking the material collected from households in the city of Rochester, NY to a windrow composter Palmyra, NY. Thus, baseline trucking costs for AD, SSF, and COM have potential to decrease if HHOM processing pathways are located within the city of Rochester, NY.

On the other hand, the model baseline made optimistic assumptions about LF pathway profitability. It was assumed that LF would not incur any capital financing costs. This may not be the case when the LF pathway requires expansion or requires debt service for its revenue-producing systems. Additionally, constant positive net income from LF gas was considered a given in the baseline model. Feedstock chemical parameters were assumed to have no significant effect on landfill gas production. This introduced an acceptable amount of uncertainty, given that landfill gas production is a small proportion of overall LF profitability (under ~15% in the model with an equal distribution of food, yard trimmings, and compostable paper). In addition, increasing moisture content and overall amounts of organic material is the primary way to boost LF gas production. Specific chemical properties (e.g. BMP, VS, sugar content) have negligible impact (Agency for Toxic Substances and Disease Registry, 2001), thus LF gas production rate was based on current LF gas yields from the local landfill receiving over 90% of HHOM from the city of Rochester, NY.

The LF pathway was not economically optimal for food, yard trimmings, or compostable paper. Even with favorable assumptions in the baseline model, at the economic optimum only the SSF, AD, and COM pathways are employed. This is not to say that there is no use for LF pathways for *all* materials, but clearly landfilling HHOM is a waste of wealth-creating resources. Although the model points to the use of three separate pathways to manage HHOM (i.e. SSF for yard trimmings, AD for food, COM for compostable paper), in a practical sense one pathway may be employed to reduce the complexity involved with simultaneously investing in three sets of infrastructure. Assuming one pathway is chosen with the current HHOM mix (61% food, 15% yard trimmings, 24%), the most profitable route is anaerobic digestion with electricity grid feed-in (Table 5.10). Under the same scenario, LF is least profitable of the four pathways examined. As such, local investment in AD infrastructure is recommended for the city of Rochester, NY alongside a pay-as-you-throw MSW pricing program to ensure feedstock access.

Table 5.10: Model baseline profitability of household organic material management pathways assuming single-stream processing

Pathway	Profitability with single-stream HHOM ($/kg)
Landfill w/ capture	$0.033
Anaerobic Digestion	$0.078
Fermentation	$0.062
Composting	$0.051

Chapter 6: Concluding remarks

The overall objectives of this research were to identify a sustainable household organic material management system in the city of Rochester, New York, and explore the environmental, social, and economic performance of system implementation. In order to recommend actions for decision-makers in the city of Rochester, NY, five main investigations were carried out. First, environmentally preferable alternatives to landfill with gas capture were identified through a literature search on local organic material management pathways. AD, SSF, and composting were found to have superior environmental performance compared to landfills with gas capture. These pathways were selected for deeper analysis after it was determined that they are locally available and feasible pathways for implementation.

From there, the social sustainability aspects of the local HHOM management system were gauged through survey and interview data. Residents in the Southeast section of the city of Rochester, NY demonstrated that compost and clean energy products made from local HHOM are demanded for purchase. Potentially these products could be used to promote community resilience (e.g. food security) through urban agriculture, given that 76% of surveyed residents grow plants for food. Data showed participation in curbside collection of HHOM is very likely considering that most residents reported willingness-to-pay for the service. Results indicated that a small economic incentive would encourage participation in source separation of HHOM and source reduction of HHMSW. These findings suggest that a PAYT fee program would be an effective way to support curbside HHOM collection service and incentivize reductions in MSW generation.

A literature review of PAYT programs in the US and globe was conducted to verify and clarify the type of PAYT project suitable for the city of Rochester, NY. A weight-based fee program was selected, based on its superior performance in MSW source reduction at lower cost than volume-based programs. Then, a CBA of the proposed PAYT program was conducted in Microsoft Excel to determine the project's budget impacts on city government and the average household. PAYT project implementation has a calculated NPV of $12,100,000-$18,100,000 over the 11 year project life. Weight-based PAYT was shown to have annual positive net cash flows between $1,300,000 (under a conservative MSW source reduction scenario) and $2,100,000 (with an optimistic source reduction scenario). At current City of Rochester solid waste collection budget levels of $17,300,000, the project would reduce annual expenditures by 7.5% to 8.2% (City of Rochester, NY 2013a). This suggests that PAYT could be effectively implemented and enable a reliable stream of source separated HHOM for private processing.

Finally, this research shed light on the economically optimal pathways for HHOM management to guide local investment in HHOM management infrastructures. By creating an engineering economic model of the four management pathways using Microsoft Excel, incumbent and alternative material management pathways were compared for profitability of HHOM processing. Baseline results indicate that $3,000,000 in profit can be made from HHOM from the city of Rochester, NY using profit-maximizing processing pathways. In the baseline, anaerobic digestion was optimal for food, SSF was optimal for yard trimmings, and composting was optimal for compostable paper. In the case of single-stream HHOM collection, anaerobic digestion was most profitable in the baseline model. Landfills with gas capture were not economically optimal for any HHOM feedstocks. Thus, decision-makers in the city of Rochester, NY have reasons to strongly consider shifting away from of landfilling as its primary HHOM management pathway. The model formulated in this research can reasonably be expanded to Monroe County and cities in New York State given the relatively localized model data set. The model can be used to make the economic case for AD, SSF, and composting – a key facet of triple bottom line benefits for HHOM management (e.g. reduced GHG emissions; improved community resilience; local agriculture opportunities; and local profit-maximization).

Future work is required in the characterization of the household organic feedstocks, particularly yard material which was not empirically examined in this work. Findings from the profit-maximization model rely on the accurate measurement of parameters. A broad sample of actual household organic material generated from city households should be analyzed for sugar content, biomethane potential, moisture content, and carbon to nitrogen ratio in order to reduce uncertainty in the model. In addition, it is essential to continue collecting data to reduce uncertainty around the costs and benefits of PAYT project implementation. For example, exploring the true costs of material trucking in the city of Rochester, NY using primary data (e.g. detailed information on truck type and time/distance required to collect material) would strengthen model conclusions. In addition, more management pathways (e.g. pyrolysis) could be added to the model to explore their potential for integration with existing HHOM management systems.

In accordance with the baseline model results, the city of Rochester, NY should focus on opening up access to the stream of household organic materials that are underutilized in the current system. Simply allowing access should be enough to activate the development of commercial utilization enterprises. Businesses respond to incentives, and the model indicates clear incentives to divert the material from landfill with gas capture to other pathways. However, in order to effectively implement any of the changes recommended by the findings in this research, a diverse group of community stakeholders must be assembled to tackle the issue. Involving community actors is what makes sustainable material management possible (Joseph 2006; Zhuang et al. 2008). There are many different variables that feed into sustainable waste management, and local expertise will be necessary for project social sustainability (e.g. participation, critical engagement). Everyone has something to gain from household organic material management – whether it is positive budget impacts, enhanced participation in local agriculture, or improved environmental quality.

The economic, social, and environmental sustainability aspects of expanded AD, SSF, and commercial composting of HHOM are promising. As such, it not advisable for the city of Rochester, NY to continue to manage HHOM with landfills. As Chapters 4 and 5 show, there are economic benefits to implementing PAYT for private development of the most profitable HHOM pathways, instead of settling for less profitable landfills. The superior financial benefits of sustainable HHOM will support robust growth of pathway infrastructure once market failures are remedied. As such, a focus of future work should be on discovering these barriers to market efficiency (e.g. political institutions, lack of information to decision-makers, non-competitive MSW management markets, externalities) and then finding ways to remove them. In the final analysis, the city of Rochester, NY will be best served by implementing PAYT with private organic collection on a pilot scale. This action will provide financial, social, and environmental benefits to the city, plus the opportunity to continue gathering data and building capacity for sustainable organic material management.

Appendices

Appendix A: Sample Calculation for HHOM landfill diversion

Using data from New York State Department of Environmental Conservation (2008):

$$Excess\ food\ diverted\ \left(\frac{MT}{yr}\right)$$

$$= 0.104\ diversion\ rate\ \times 16{,}624\ MT\ household\ generation\ of\ excess\ food/year$$

$$= 174\ MT/yr$$

$$Excess\ food\ not\ diverted\ \left(\frac{MT}{yr}\right)$$

$$= 16{,}624\frac{MT}{yr} household\ generation\ of\ excess\ food$$

$$- 174\frac{MT}{yr} diverted\ excess\ food = 16{,}450\frac{MT}{yr}$$

The same process was followed to calculate yard trimmings and compostable paper diverted and not diverted by substituting in their specific diversion rates and household generation per year.

Appendix B: Household organic material management survey questions and answers

Aspect	No.	Question	Answers
General	1	How likely would it be for your household to produce less garbage if it saved money to do so?	Very unlikely; Unlikely; Neither likely nor unlikely; Likely; Very likely
	2	If available, how likely would it be for your household to participate in an organic material collection program if it saved money to do so?	See #1
	3	Does your household compost organic material at home?	Yes; No
	4	If you answered no, please briefly explain why you do not compost your separated household organic material at home.	Short answer
Economic	5	What is the most your household would be willing to pay (or need to be paid) for curbside collection of organic material that you separated from your garbage?	Pay $10+; Pay $5-$10; Pay $0-5; Pay $0; Be paid $0-$5; Be paid $5+
	6	Would you accept having your household organic material and garbage separately collected every two weeks?	Yes; No; Do not care
	7	What is the most your household would be willing to pay (or be paid) for a community drop-off point for organic material that you separated from your garbage?	Pay $10+; Pay $5-$10; Pay $0-5; Pay $0; Be paid $0-$5; Be paid $5+
	8	What is the farthest from your home you would travel to a community drop-off point to deposit your household organic material each week?	0 miles; Under 1/2 mile; 1/2 to 1 mile; 1 to 2 miles; 2 to 3 miles; 3 to 4 miles; 4 to 5 miles; over 5 miles
	9	Are you interested in purchasing local renewable energy made from city household organic material?	Yes; No
	10	Are you interested in purchasing local compost made from city household organic material?	Yes; No
Social	11	"I am conscious of the social impacts of throwing away my household organic material to the landfill"	Strongly disagree; disagree; neither agree nor disagree; agree; strongly agree
	12	"I have a desire for more local community engagement with my neighbors."	See #11
	13	On average, how many of your individual neighbors do you interact with each week?	0;1;2;3;4;5;6+
	14	Are you interested in growing your own food?	Yes; No
	15	Please indicate what you have grown in the past year.	Food only; Edible herbs only; Inedible plants only; Food, edible herbs, inedible plants; Food and edible herbs; Food and inedible plants; Edible herbs and inedible plants
	16	Where do you grow your plants?	Community garden/greenhouse; Home garden/greenhouse; Both

Aspect	No.	Question	Answers
Environmental	17	"I am conscious of the environmental impacts of throwing away my household organic material to the landfill"	See #11
	18	"I have a desire to improve the environment."	See #11
	19	"I prefer that my household organic material be made into energy or compost instead of going to a landfill."	See #11
	20	Please rate your familiarity with using anaerobic digestion to make methane from organic material.	Completely unfamiliar; Somewhat unfamiliar; Neither familiar or unfamiliar; Somewhat familiar; Very familiar
	21	Please rate your familiarity with using composting to make soil amendments from organic material.	See #20
	22	Please rate your familiarity with fermentation to make ethanol fuel from organic material.	See #20
	23	Please rate your familiarity with using landfill gas capture to make methane biogas from organic material.	See #20
	24	"Organic material (such as food, yard trimmings, and compostable paper) is not waste."	See #11
Demographics	25	What is your zip code?	14606 - 14624
	26	Sex	Male; Female
	27	Racial and ethnic identity	Multi-racial; Hispanic; White; Black; Asian; American Indian or Alaska Native; Pacific Islander; Other
	28	Age	-
	29	Household income	-
	30	What type of residential building do you live in?	Single family home; Multi-family home or apartment building

Aspect	No.	Question	Answers
Participation in HHOM separation/collection	31	Did your household compost organic material before you joined Community Composting?	
	32	Overall, how satisfied are you with your experience participating in Community Composting?	Very satisfied; Satisfied; Neither satisfied nor dissatisfied; Dissatisfied; Very dissatisfied
	33	Why did you decide to join Community Composting?	Short answer
	34	Please list the problems you have faced separating your organic kitchen material for weekly collection. Rank them starting with #1 as the top problem.	Short answer
	35	Please list the benefits you have enjoyed from separating your organic kitchen material for weekly collection. Rank them starting with #1 as the top benefit.	Short answer
	36	"Since I began separating my organic material for collection by Community Composting, my level of interaction with my neighbors has increased."	See #11

Appendix C: Interview Questions

Awareness

Q: What comes to mind when you hear sustainable organic material management?

Q: Is there a more useful way you would refer to what I call sustainable organic material management?

Q: Why are you interested in organic material management?

Q: Are you currently engaged in any organic material management initiatives? WHAT

Q: Do you participate in CC?

Q: What do you think about the Community Composting program?

Q: How has participation influenced your thinking? Behavior?

Q: How would you go about engaging others in the organic management process?

Q: Have you tried to get your neighbors to participate with you to bring down costs?

Q: Why or why not?

Q: What do you think is needed to get more people to participate in organic recycling using their kitchen material?

Q: Do you foresee any other barriers to implementation?

Processes

Q: What are the benefits you derive from participating in organic management?

Q: What are the challenges you face in participating in organic management?

Q: Would you find a community drop-off point for your organic material to be useful?

Q: What would you need for it to work for you?

Q: If curbside pickup for your discarded kitchen material was available through the city as part of your regular collection, would you find that useful?

Q: What would that need to be like for it to work for you?

Agriculture

Q: Do you grow your own food?

Q: What has your experience been with that in relation to your organic management?

Waste

Q: Why don't you see organic material as waste?

Appendix D: Community Composting Pricing

The pricing scheme for Community Composting was developed in order to encourage neighborhoods and businesses to get signed up for the program. There is a clear incentive to involve others; there is a one-time $15 dollar credit given to composters that sign up others and lower prices for shared plans. Subscribers can choose to share a curbside pickup location with their neighbors to reduce the price of picking up their bucket. A single subscriber can have one bucket serviced each week at a cost of $6.92 per pickup. But if two neighbors share a plan and get one bucket each, the price per pickup falls to $4.38 (a 37% decrease). Additional price reductions can be gained through a yearly billing option, encouraging long-term participation. Table 1 shows the Community Composting pricing plan with monthly billing, and Table 2 shows the pricing plan for yearly billing.

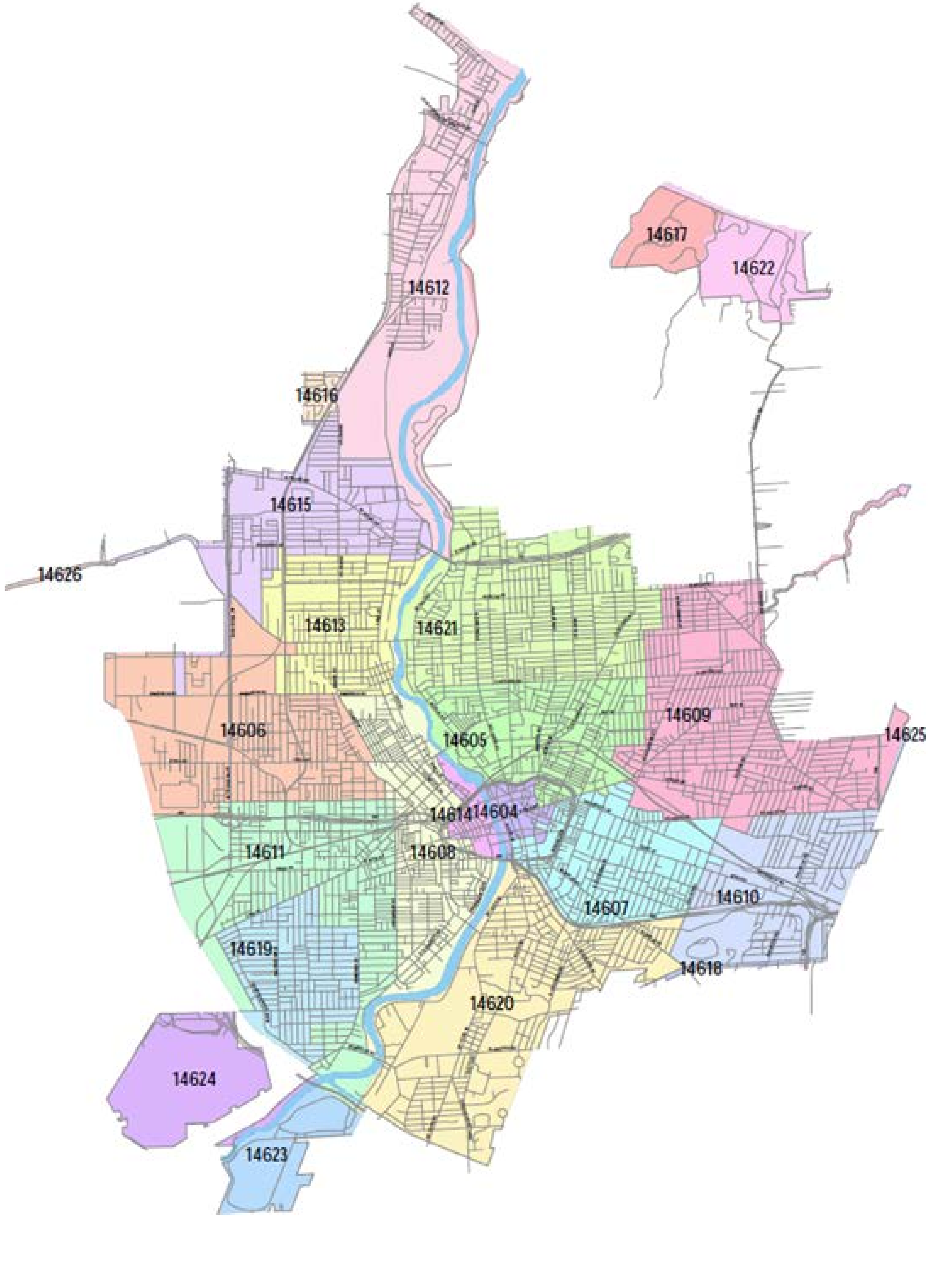
Table 1: Community Composting pricing, monthly billing

Number of households subscribing	Price per pickup ($)	Nominal decrease ($)	Percent decrease
1	6.92	N/A	N/A
2	4.38	2.54	37%
3	3.54	0.84	19%
4	3.12	0.42	12%
5	2.86	0.26	8%
6	2.69	0.17	6%
7	2.57	0.12	4%
8	2.48	0.09	4%
9	2.41	0.07	3%
10	2.35	0.06	2%

Table 2: Community Composting pricing, yearly billing

Number of households subscribing	Price per pickup ($)	Nominal decrease ($)	Percent decrease
1	6.00	N/A	N/A
2	3.75	2.25	38%
3	3.00	0.75	20%
4	2.63	0.37	12%
5	2.40	0.23	9%
6	2.25	0.15	6%
7	2.14	0.11	5%
8	2.06	0.08	4%
9	2.00	0.06	3%
10	1.95	0.05	3%

Appendix E: City of Rochester, NY Zip Codes



Appendix F: Composition of excess food and compostable paper sample used as model input

Food (representative of US diet)

Category	Description	Mass (g)	Percent in sample of urban excess food	Percent in average US diet of 2000 (USDA 2001)
Fruit	Banana peel	122	12%	14%
	Lime rind	23	2%	
	All fruit	145	14%	
Vegetables	Onion with skin	169	17%	22%
	Avocado rind	38	4%	
	Sweet potato skin	13	1%	
	All vegetable	220	22%	
Dairy	Cheddar cheese	31	3%	30%
	Greek yogurt	23	2%	
	Cottage cheese	250	25%	
	All dairy	304	30%	
Grain products	Spoiled bread	43	4%	10%
	Millet	12	1%	
	Fresh bread	47	5%	
	All grain products	102	10%	
Added fats/oils	Fresh soybean oil	38	4%	4%
Added caloric sweeteners	White sugar	78	8%	8%
Meats	Tuna fish	116	12%	10%
Other	n/a	0	0%	2%
Grand total	-	1003	100%	100%

Compostable paper

Content	Grams
White paper towels	90
Tea bags	10
Representative US food waste	100

Appendix G: Trucking costs avoided (truncated raw data)

MSW charge ($/kg)	Municipal organic collection			Private organic collection		
	High source reduction estimate	Mid source reduction estimate	Low source reduction estimate	High source reduction estimate	Mid source reduction estimate	Low source reduction estimate
$ 0.00	$0	$0	$0	$866,079	$866,079	$866,079
$ 0.10	$125,919	$92,136	$7,678	$956,489	$932,232	$871,592
$ 0.20	$251,839	$184,272	$15,356	$1,046,899	$998,386	$877,104
$ 0.30	$377,758	$276,408	$23,034	$1,137,309	$1,064,540	$882,617
$ 0.40	$503,677	$368,544	$30,712	$1,227,719	$1,130,694	$888,130
$ 0.50	$629,596	$460,680	$38,390	$1,318,129	$1,196,847	$893,643
$ 0.60	$755,516	$552,816	$46,068	$1,408,539	$1,263,001	$899,156
$ 0.70	$881,435	$644,952	$53,746	$1,498,949	$1,329,155	$904,668
$ 0.80	$1,007,354	$737,088	$61,424	$1,589,359	$1,395,308	$910,181
$ 0.90	$1,133,273	$829,224	$69,102	$1,679,769	$1,461,462	$915,694
$ 1.00	$1,259,193	$921,360	$76,780	$1,770,179	$1,527,616	$921,207
$ 1.10	$1,385,112	$1,013,496	$84,458	$1,860,589	$1,593,769	$926,720
$ 1.20	$1,511,031	$1,105,633	$92,136	$1,950,999	$1,659,923	$932,232
$ 1.30	$1,636,950	$1,197,769	$99,814	$2,041,409	$1,726,077	$937,745
$ 1.40	$1,762,870	$1,289,905	$107,492	$2,131,819	$1,792,230	$943,258
$ 1.50	$1,888,789	$1,382,041	$115,170	$2,222,229	$1,858,384	$948,771
$ 1.60	$2,014,708	$1,474,177	$122,848	$2,312,639	$1,924,538	$954,284
$ 1.70	$2,100,186	$1,520,438	$122,848	$2,374,012	$1,957,753	$954,284
$ 1.80	$2,174,428	$1,562,830	$122,848	$2,427,318	$1,988,191	$954,284
$ 1.90	$2,239,420	$1,601,865	$122,848	$2,473,982	$2,016,218	$954,284
$ 2.00	$2,296,714	$1,637,966	$122,848	$2,515,120	$2,042,138	$954,284

Avoided trucking cost parameters	Value	Source
Billable city households	86,150	US Census (2010)
Price	$0.00 to $3.00	CBA model
Baseline HHMSW generation	96,652,974 kg	NYSDEC (2008)

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